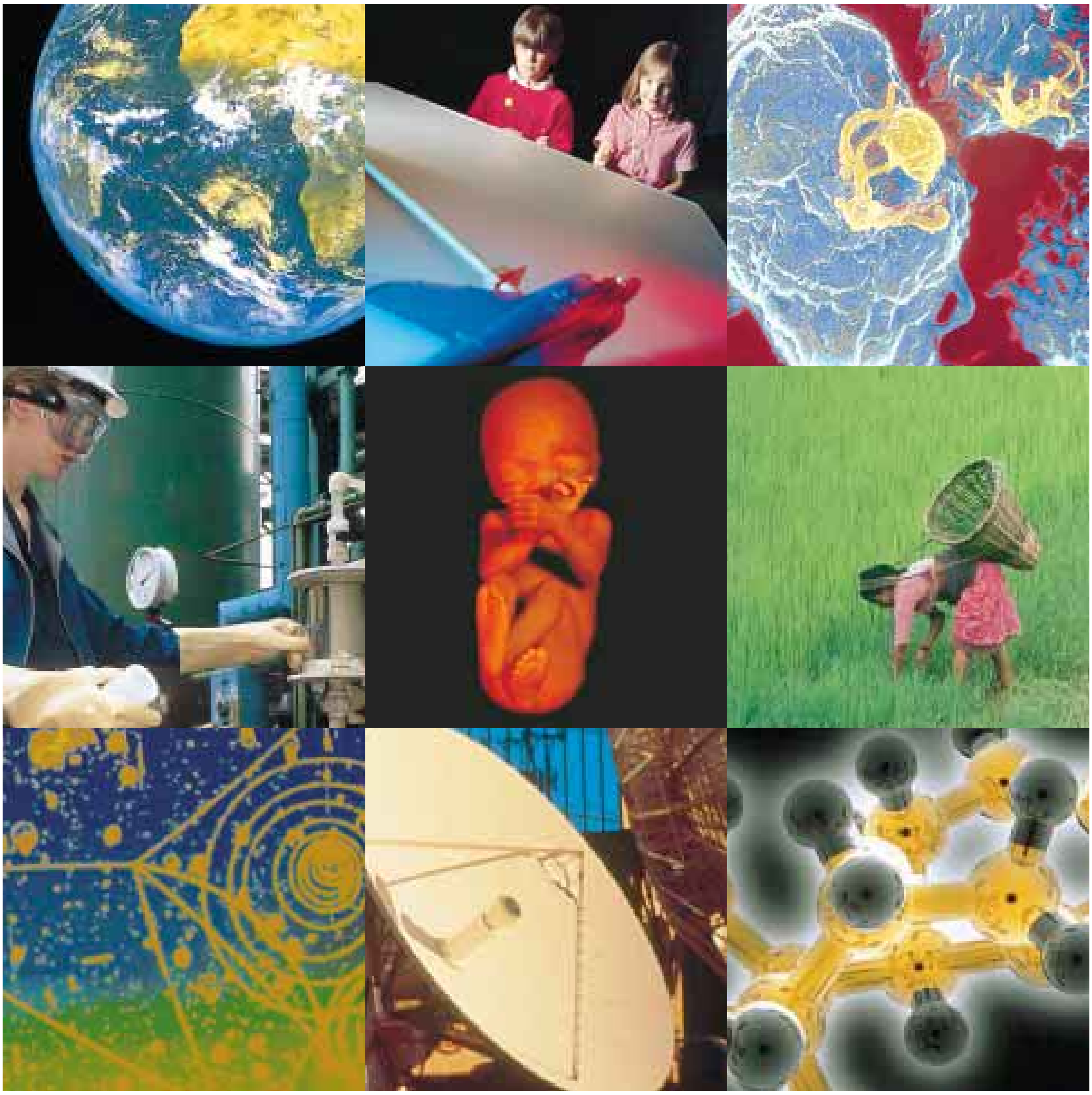
WORLD CONFERENCE ON SCIENCE



SCIENCE FOR THE TWENTY-FIRST CENTURY
A New Commitment

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UNESCO

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Preface

The World Conference on Science in June 1999 sought to strengthen the ties between science and society. As the incoming Director-General of UNESCO and President of ICSU, we should like to pay tribute to our respective predecessors, Federico Mayor and Werner Arber, for this ambitious endeavour.

The Conference came in response to a dilemma: public support for science appears to be wavering and yet scientific research and technological development have become more necessary than ever to solve some of the most pressing problems facing humankind. This situation calls for a new commitment – a new social contract – whereby scientists pledge to be responsive to these needs and governments pledge support for research.

This commitment appears clearly in the two key documents adopted by the Conference. We believe they will prove to be precious tools in the years to come for all stakeholders committed to seeing science harnessed more effectively for the promotion of human well-being and sustainable development. For our part, we pledge our own personal commitment and that of our respective organizations to fostering wide implementation of the Conference recommendations.

UNESCO and ICSU will continue to assume their complementary roles as catalysts of this new commitment. Mobilization first requires widespread dissemination of information. The outcome of the Conference, including the publication of the present Proceedings, will be transmitted via our respective networks. UNESCO, with its national commissions and field offices, not to mention its close ties with sister organizations of the United Nations system, is rightly proud of its extensive intergovernmental network and of its important relays at the grass-roots level through ties with hundreds of non-governmental organizations around the world. ICSU links hundreds of thousands of scientists worldwide through scientific academies and research councils, scientific unions and associates and is thus representative of the world scientific community.

Time will tell if the World Conference on Science has succeeded in its aim of fostering closer mutual ties between the scientific community and society at large. A better awareness of each other's needs and expectations should translate in the next decade into a myriad of concrete initiatives. We hope these will include the orientation of science towards sustainable human development and the better management of the environment. We also hope to see greater funding of science education and public research, and more frequent recourse by scientists to communication through non-specialist media.

Initiatives reflecting this new commitment need not be top-down. Rather than waiting for national policy changes, for example, it is hoped that the practitioners of science will launch initiatives themselves in teaching and research, which should then attract government support.

The Budapest Conference has already triggered a number of new projects and partnerships. We expect there to be a multiplier effect over the next few years. UNESCO and ICSU will monitor progress in the implementation of follow-up – as they were asked to do in the Conference recommendations – including a joint analysis of the first outcomes to be completed by the end of 2001. We are counting on all the stakeholders in science to make that a very full report.

Koichiro Matsuura
Director-General
UNESCO

H Yoshikawa

Hiroyuki Yoshikawa
President
ICSU

Introduction

Background

The seeds of modern science sown three centuries ago have since grown and multiplied in an outstanding manner. Innovations stemming from scientific knowledge have been greatly beneficial to humankind. Life expectancy has increased strikingly and cures have been discovered for many diseases; agricultural output has increased enormously; and technological developments and the use of new energy sources have created the opportunity of freeing humankind from arduous labour. Today, science and scientific applications exert a profound influence on society – the very organization of society itself owes much to scientific thinking – and the role of science promises to be even greater in the future because of accelerating scientific advances.

However, scientific and technological progress has also made possible the construction of sophisticated arms that have the potential to destroy life on the entire planet. Meanwhile, humanity is being confronted with problems on a global scale, many provoked by the mismanagement of natural resources, or unsustainable production and consumption patterns. It will take a considerable amount of scientific research to find ways to repair the damage. Societal change being slow, it may still take many years for sustainability to become a household concept; yet there is no time to lose, for there are strong indications that human activity is the cause of environmental changes that can have serious repercussions for the planet’s ecological equilibrium in the coming century.

Scientific research alone will not suffice; it will need to be accompanied by a strong political will – and public support – if we are to transmit to future generations a world that today’s citizens would want to live in. And for mentalities to change, the scientific community must learn to dialogue with society in order to obtain the means of tackling effectively today’s pressing social and environmental problems.

For a long time, scientists proclaimed that science was neutral. At the end of the 19th century, scientists concerned about the influence of financial considerations on the choice of research subjects claimed that ‘pure’ science should be pursued because its findings were building blocks of the ‘cathedral of knowledge’. Pure science, they argued, should not be confused with ‘applied’ science, the latter being oriented toward problem-solving. In 1945, Vannevar Bush, the US presidential adviser for science, proposed the concept of ‘basic’ versus ‘applied’ science: basic science generated knowledge that would eventually find its way into applications. Although Bush clearly acknowledged the social aspects of scientific progress and the necessity of linking science to social needs, the scientific community has used Bush’s concept to claim that basic science is neutral and therefore cannot be blamed for any misuse it is put to.

The ‘neutral’ mentality may be acceptable in those sectors of science where applications cannot be foreseen and in an academic structure that does not interact with industry and the business community. However, in recent decades, the scientific community has gone through a metamorphosis. The interaction between universities and industry has become commonplace in industrialized countries and is encouraged everywhere. Moreover, funding agencies allocate financial resources preferentially to applied research projects. Many scientists are personally involved with applications of research and industrial activities. Military applications of science have been of enormous consequence. Therefore, scientists can no longer claim today that their work has nothing to do with social issues. It is interesting to recall the plea made by Albert Einstein back in 1931: ‘concern for humankind itself and its fate must always form the chief interest of all technical endeavours. . . . Never forget this in the midst of your diagrams and equations’.

The success of science was until recently linked to the reductionistic approach, through which simple model systems are studied in order to reach conclusions that are extrapolated to explain natural phenomena. However, a few decades ago, scientists began studying complex systems and today are struggling to identify appropriate ways to derive relevant results. Conclusions based on the study of complex systems generally involve high degrees of uncertainty. Since public decision-making often requires the analysis of complex systems, this uncertainty contributes to undermining the public trust that science has enjoyed until today.

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The United Nations Educational, Scientific and Cultural Organization (UNESCO) and the International Council for Science (ICSU) decided that representatives of government, the scientific community and other stakeholders in science needed to sit down together to debate what efforts should be invested to make science advance in response to the expectations of society and the challenges posed by human and social development. This unique forum – the World Conference on Science – was convened by UNESCO and ICSU, in cooperation with other partners, from 26 June to 1 July 1999 in the city of Budapest and hosted by the Government of Hungary.

Close partners in science for the past 50 years, UNESCO and ICSU assumed complementary roles in the venture and were able to address and involve representatives of all stakeholders in science: national governments and institutions, educational and research establishments, the scientific community, the industrial sector, the specialized agencies of the United Nations system and other intergovernmental organizations, international scientific unions, the media and other sectors of society.

Preparatory phase

The World Conference on Science was conceived as a process consisting of a preparatory phase, the Conference itself and a follow-up programme. Within UNESCO, the Science Sector worked in close collaboration with the Social and Human Sciences Sector in the preparation of the programme and key documents. The members of the International Scientific Advisory Board of UNESCO and of the International Scientific Organizing Committee for the Conference played an important role in the formulation of the programme. UNESCO and ICSU invited their many partners to associate their conferences, meetings and other events with the Conference in order to raise awareness on science and mobilize general debate worldwide. A total of 69 meetings organized around the world between June 1995 and June 1999 were associated with the Conference and 52 reports issued by these meetings were submitted to Budapest. In this way a wide range of scientists, decision-makers and representatives of the public were able to make an important input to the Conference even if not attending the central event.

A website (www.unesco.org/science/wcs) was created to diffuse information and for consultation. An interactive youth page was instrumental in involving young scientists. The website now contains a wealth of useful information concerning the Conference.

The Conference documents

Two primary documents were prepared jointly by UNESCO and ICSU for examination by the Conference:

- *Declaration on Science and the Use of Scientific Knowledge* (*Declaration*), underscoring the political commitment to the scientific endeavour and to the solution of problems at the interface between science and society; and the
- *Science Agenda – Framework for Action* (*Science Agenda*), defining guidelines to orient the action of the different categories of participant to the Conference.

In the months preceding the Conference, both draft documents were distributed by UNESCO and ICSU to stakeholders in science around the world as part of a wide consultation process that included: the above-mentioned International Scientific Advisory Board and International Scientific Organizing Committee; all national delegations and national commissions of UNESCO; scientific academies and national research councils; the international scientific unions of ICSU; intergovernmental organizations, including organizations of the United Nations system, and non-governmental organizations.

The *Declaration* and the *Science Agenda* were revised a number of times in response to comments and suggestions from partners in the Conference. They were subsequently distributed for final approval to participants in Budapest, along with an *Introductory Note to the Science Agenda* which, unlike the other two documents, would not be subject to negotiation.

The Conference

Participants included over 1 800 delegates representing 155 countries, 28 intergovernmental organizations and more than 60 international non-governmental organizations; and approximately 80 ministers of science and technology, research and education or their equivalents attended. National delegations were of a mixed nature, being made up mainly of government officials and scientists. The Conference also attracted more than 250 journalists from around the world.

The Conference programme was made up of three major forums. Forum I focused on a number of scientific topics of particular relevance; it addressed the intellectual, institutional and economic challenges the scientific endeavour faces today and the ample opportunities that science offers for problem-solving in the years to come; Forum II examined the interfaces between science and society and dealt with social requirements and expectations, ethical issues and the public understanding of science; Forum III sought an increased commitment to science by governments, policy-makers and other partners, and obligations towards society on the part of the scientific community.

Forums I and II consisted of plenary sessions at which the broad issues were aired, followed by a total of 25 concurrent thematic meetings spread over two days. They were organized in cooperation with a large number of bodies and benefited from the participation of specialists of worldwide renown. The summaries of the presentations made at these meetings are contained in this volume. Two synthetic texts were prepared by ICSU and a third jointly by the Third World Academy of Sciences and by the ICSU Committee on Science and Technology for Development to serve as background documents to the discussions in Forums I and II. These background documents may be consulted at the World Conference on Science website.

Forum III consisted of a single plenary debate during the course of which the national delegations and a number of non-governmental and intergovernmental organizations took the floor to outline their vision of science in the 21st century.

A number of *ad hoc* events were held in parallel with the official Conference programme to take advantage of the large numbers of ministers, high-ranking officials and internationally recognized scientists attending the Conference.

Satellite events involving stakeholders in science were organized by the Hungarian Local Organizing Committee. These included a Forum of Young Scientists, which attracted 150 young scientists and pre-scientists from 57 countries. The forum prepared a Statement containing a number of recommendations that were subsequently incorporated into the Conference's two primary documents and resolved to create a permanent International Forum of Young Scientists. A consultation of non-governmental organizations also took place and the Statement coming out of this meeting was presented in Forum III.

The *Declaration* and the *Science Agenda* were thoroughly revised by the Drafting Group, which was open-ended in nature but which had a core membership of 12 representatives nominated by the six UNESCO electoral groups, one from ICSU, two from other international non-governmental organizations, one from the bodies of the United Nations system and one from intergovernmental organizations outside the system. Approximately 50 submissions containing more than 500 amendments were considered over a two-day period and were dealt with by consensus.

At the final session of the Conference on the afternoon of 1 July 1999, the participants adopted unanimously the *Declaration* and the *Science Agenda* as amended by the Drafting Group. The present volume contains the texts of both documents in their final, approved form, as well as the *Introductory Note to the Science Agenda*, which gives useful background to the latter. All three texts may also be consulted at the World Conference on Science website.

The *Declaration* and *Science Agenda* were subsequently approved by the ICSU General Assembly and by the UNESCO General Conference. The General Conference further invited the Director-General to transmit both documents to the Secretary-General of the United Nations for appropriate action.

Future activities: follow-up initiatives

UNESCO and ICSU are now committed to playing a central role in ensuring that the recommendations of the Conference are implemented. Although the follow-up to the Conference will involve many partners – governments, UN bodies, universities and research institutions, scientists and the scientific community, funding agencies, intergovernmental and non-governmental organizations and the private sector – the World Conference on Science has entrusted UNESCO with the special task of acting as a promoter and a clearing-house for all activities and initiatives, in cooperation with ICSU. Priority issues highlighted by the participants to the Conference and which will be the subject of follow-up action are: sharing of scientific knowledge and information; science education at all levels; communication of science and improvement of public understanding; meeting basic human and social needs; problems of environment and sustainable human development; interaction of science with industry and the private sector; involvement of women and young people in all science-related activities; ethics of science; traditional knowledge; and national policy-making in science and technology. Many of these issues are interdisciplinary and therefore, in carrying out the follow-up plan, UNESCO will involve all its fields of competence.

The World Conference on Science has already launched a number of new projects and partnerships which are expected to trigger a dynamic response from the research community in the form of proposals for redefining existing research priorities in every country. May I also take this opportunity to urge the practitioners of science not to wait for top-down national policy changes but rather to launch immediately initiatives that will then attract government support? We are counting on the practitioners of science to create a 'multiplier effect'.

I appeal to those involved in the World Conference on Science to keep UNESCO abreast of their follow-up action.

In turn, UNESCO and ICSU will develop – together with their partners – concrete initiatives oriented towards strengthening international scientific cooperation.

The Conference documents represent a worldwide vision of the role natural sciences should play in the coming century and a renewed reciprocal commitment on the part of the natural sciences and society. I should like to invite readers who could not be present at Budapest to contribute, through their own words and deeds, to making the goals of the *Declaration* and *Science Agenda* a reality.

The World Conference on Science was the result of a collective effort made by many organizations, institutions and individuals. Without them, the Conference would not have been possible and I thank them wholeheartedly.

M. Iaccarino

Maurizio Iaccarino
Assistant Director-General for Natural Sciences, UNESCO
Secretary-General of the World Conference on Science
January 2000

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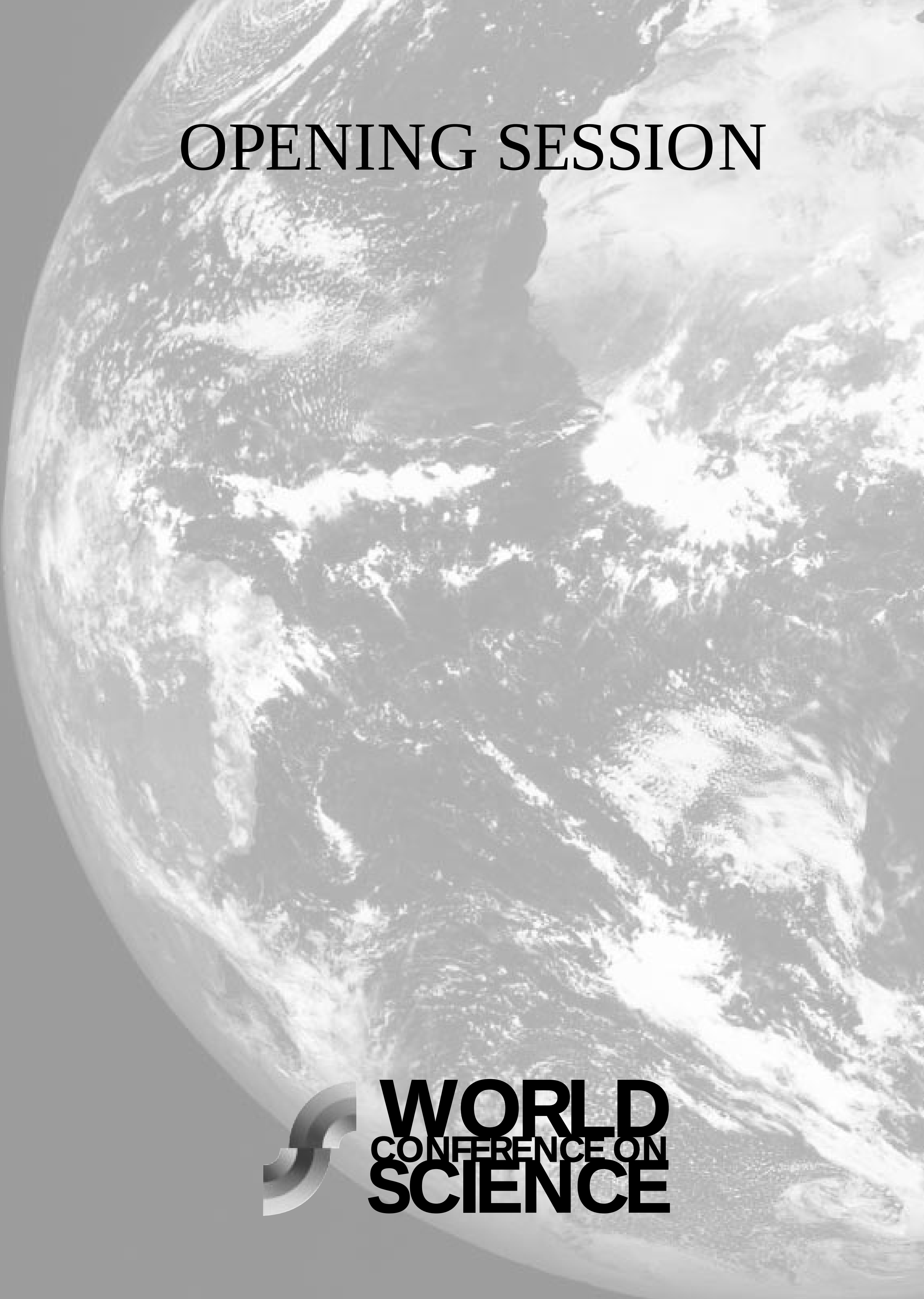

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Opening address

Árpád Göncz
President, Republic of Hungary

Welcome to Hungary, welcome to Budapest! It is a unique and uplifting occasion for us: on the threshold of a new millennium Hungary hosts the World Conference on Science and serves as a home to a world of diversity and, at the same time, a world of unity.

It must be a historic and thrilling challenge for you: to take stock of the achievements and shortcomings of science in the 20th century and have a common vision of the relationship of science and society in the 21st century. The participants in this Conference represent different countries, languages, cultures, religions, organizations, professions, colours of skin, genders. But I do believe you are united by at least three common denominators, namely: there is only one science, there is only one planet Earth and there is only one humankind.

My Chief of Protocol told me that I am entitled to address you in my mother tongue. So, allow me, please to shift to another world language: Hungarian, which is widely spoken all over the world – by Hungarians.

Every single moment of people's destinies and of the history of humankind is one and cannot be repeated; therefore they are all unique and very valuable. Nevertheless, there are some especially unique and valuable dates and events in history. In some cases we find out only later that history had been written; in other cases we know in advance that history is being made. I consider the World Conference on Science to be a historic event.

When we think only of the overwhelming events of this past decade we can consider the evaluation of this single decade a brave venture and a great challenge. As a Hungarian I can say of the world that a political and social revolution took place in our country and in our region that we could hardly imagine 10 years ago but which we always believed in and which we always hoped for. At the same time 'World War Three', I mean the Cold War, ended. These events opened new ways for a radical transformation of Hungary's network of international relations and for the redefinition of our opportunities and responsibilities.

In the meantime, the explosion of globalization and the information revolution took place. All of us had to realize that we live in the same global village and that we, as individuals, small communities and countries are responsible for our destinies and for the future of our Earth and of humankind as a whole. We have to share responsibility for what we have to, and can only, solve together; we are responsible for setting the course of sustainable development for humankind, for creating harmony between human beings and nature, for bringing peace and well-being to all the countries and inhabitants of our planet. I am convinced that the great global equilibrium will result from the sum of thousands and thousands of small, local sets of balances. The global village will be habitable in the long run only if every single house in it becomes a home, if every single family in it grows day by day financially, intellectually and spiritually as well.

If we try to capture 10 years of the past, and if we look only 10 years into the future, even then our task is enormous. Yet you, the participants in this World Conference on Science, have come together to summarize the development of science in the 20th century, to see the extent to which science has contributed to solving social problems and to outline the whole system of relationships between science and society in the 21st century. A very daring venture, indeed! However, you, scientists and researchers, people who transform the results of scientific and technological development into social and economic values, know better than anyone else that there is no progress, neither scientific nor social, without innovation and creativity, without brave action.

Looking at my own age (not the information age, but rather the number of years I have lived) I can say that, when I was born, Albert Einstein's theory of relativity was the intellectual 'game' for a few dozen ingenious physicists. Aviation was in its infancy, even motoring was a luxury reserved for only a few tens of thousands. The nuclear chain reaction, television, integrated circuits, personal computers were dozing at the depth of human imagination, awaiting awakening and creation. Epidemics and widespread diseases decimated the population; however, by now science has already found the remedy for them. Biotechnological processes, certain scientific and technological solutions which multiply agricultural production many times over have become everyday practice, yet at the time even the concepts were unknown. When I was born in the 1920s, some works of imagination had already been created about the Earth as 'suspended' in space, but still lots of years had to pass before the first space photo of our planet was taken that could be considered as epoch-making. Looking at this space photo, and later on at others, we were awed and shocked to realize how beautiful and at the same time how fragile our planet was – and still is. While the astronomers look millions of light years away into the universe travelling far away in space and can capture billions of years back in time, we want to question the future. What will tomorrow bring, what can we do to make the balance of the undoubtedly great scientific and technological progress of the 20th century even more positive for society, how can we serve humankind even better?

To bridge the gap between past, present and future – this is our greatest challenge. First we have to be able to build bridges in spirit and intellectually, going deep down and finding the 'laws', so that these bridges can really be built, not only in time, but in space as well. We have to build bridges among people and countries, among small and large communities. We have to create bridges of understanding and unity among our diverse differences.

Right in the draughty middle of Central Europe, as an inhabitant of a country with a stormy past, having the experience I have, I dare say that only values which are created together can become common values; a solution is a lasting one only if it takes differences among people into account; and only those interests which recognize and appreciate each other are capable of creative cooperation. This is the message I get from my own country's history. Surely, many of you know that Hungary and the Hungarians are preparing to celebrate the 1 000th anniversary of the founding of their state. In the year 2000, it will be 1 000 years since the first Hungarian king, Saint Steven, was crowned, who, as a long-term thinker and a practical organizer, laid the foundations for the state of Hungary. The ideals and the teachings of Saint Steven the First are still valid in a lot of respects. His humanism, his love of his country, his respect for other nations still send a message from the distant past to the present; they still encourage Hungarians and non-Hungarians to embrace wisdom, tolerance and perseverance. When my thoughts run through the past 1 000 years full of anguish and suffering, destruction and self-destruction, sometimes I ask myself with pain: did this have to happen? But finally optimism and cheerfulness overcome me: we have survived and hopefully the worst is already over. Everything this country has done in the past 10 years in establishing political democracy, in creating a market economy and in social progress can justly be called historic achievements.

We are all obliged to learn from our past. However, learning the lessons of history is not enough to avoid the traps of the future. We need forums such as this present one, which 'maps' the global problems of humankind and very responsibly shows us the way to the coming century.

When we look at the 20th century, it is difficult to express its essence by just a single adjective. Is this the century of world wars, of a nuclear age, of aviation and space, of biotechnology or of the information revolution? I think it is all of them together. However, it is frightening and should serve as a warning that, in the 20th century, humankind reached such a level of technical development that it has become capable of destroying itself, as well as the Earth. How will we characterize the 21st century then? I do not know; I can tell you only my hopes. I hope that the oncoming century will be the age of responsible knowledge, when scientific achievements will be used for the benefit of humankind, for maintaining peace and for creating prosperity. I hope the 21st century will be the age of wisdom.

The great scientists of our century were also the greatest thinkers of our times, who have had lasting effects on the relationship between science and society. I hope I am not too biased if I quote a few useful thoughts of a Hungarian-born scientist and genius, János Neumann (John von Neumann), who among others was a pioneering figure of modern computing and the founding father of game theory. In 1955 he published a strategic study entitled 'Can We Survive Technology?' He wrote: 'The Globe is in a fast maturing crisis… The technology which is just developing and will rule the next decades totally contradicts the traditional and especially the currently valid geographical and political units and concepts.… There is no remedy against development'. Then he draws the following conclusion: 'It would not be wise to ask for a ready-made recipe. Only the necessary human characteristics can be defined: tolerance, flexibility, and intelligence.' Later he adds: 'and a good sense of humour'. I do believe that these thoughts and recommendations are still valid today.

Lastly, I would like to wish you a very successful Conference, which, hopefully – besides the hard work – will be a fiesta of science, a celebration of knowledge and a cheerful forum of wisdom. Enjoy your stay in Hungary as much as we enjoy hosting every one of you and the World Conference on Science as a whole.

Opening address: Science in the 21st century

Ferenc Glatz
President, Hungarian Academy of Sciences

On behalf of the Hungarian Academy of Sciences and the entire Hungarian scientific community, it is a great privilege for me to welcome all the participants to the first World Conference on Science here today. First of all, I think I am speaking not only for Hungarian researchers but for scientists from every nation represented here when I express our gratitude to the leading officials of both UNESCO and ICSU, not only for proposing this Conference but also for all the efforts they have invested in bringing this meeting to fruition.

In addition, we must express our special thanks to the UNESCO and ICSU officials for proposing that the very first World Conference on Science be arranged in a region – in East-Central Europe, more precisely in Hungary – where programmes of great significance are being designed and implemented in the fields of economics and technology. For me, this sends a clear message: we must believe that science may be the most important means to level out the immense social and economic differences which now exist in the world. We can recommend that every economically underdeveloped region embark on this path towards realignment with the more advanced regions. This process should begin with such developments as the improvement of the quality of the workforce, with people seeking to obtain high-level scientific qualifications, or the formation of a highly qualified local scientific and technological elite. This should all be achieved by giving high priority to the support of public and higher education and science.

The present World Conference on Science forms part of an extensive worldwide series of conferences sponsored by UNESCO. One such conference on cultural policy was recently held in Stockholm in 1998 (World Conference on Cultural Policies for Development); another focusing on higher education took place in Paris also in 1998 (World Conference on Higher Education); and now we are gathered here for the start of the present Conference on Science. As a scholar of cultural history, I deem these meetings both highly topical and very pertinent. Indeed, it was the past decade that suddenly made mankind realize that a new epoch has opened in the life of our world cultures (irrespective of whether we are at the end of the 20th century according to the Christian calendar, or whether we are counting in the Islamic, Chinese, Buddhist or Jewish calendars and whether we term the coming century 21st or nth century).

We have suddenly come to realize that the advent of the age of informatics has opened a newer age in the scientific and technological revolution. It is now clearer to us than ever before that the driving force behind modern developments in our earthly cultures was and still is a series of scientific and technological revolutions which started back in the 18th century and which over the past 30 years has brought us into the informatics age. As we look back today it is this rapid development which warns us that scientific and technological revolutions have always gone hand in hand with corresponding changes in everyday life within our societies.

The machine age of the 18th and 19th centuries and, within this, the development of iron processing, and in turn that of combustion and electrical engines, not only fully transformed such fields as communication, organization of labour and industrial plants, production of material goods and foodstuffs, but also revolutionized the structure of settlements as well as the daily contact between people, enriched people's knowledge and widened their scientific horizons; at the same time, it promoted the development of individual national languages. They changed people's culture of communication and even their emotional experience. In the same way, in our age, informatics will profoundly change the production and communication systems of cultures in our present-day world.

This newer stage of world development will upgrade globalization but not only economically; the organization of production, commerce and regional administration as well as cultural contexts will be affected. Presently, concomitant with the current scientific and technological revolution, a social and cultural revolution is taking place.

We researchers may proudly declare that the foundations of the scientific and technological revolution rest on the achievements of scientists. But, pride aside, we must also demonstrate a sense of responsibility: what kind of social effects will this scientific and technological boom have? For what purposes will society – economics and politics – use the research findings? It is also our task to establish the possible alternatives mankind may have to choose between. The conferences in Rio de Janeiro (United Nations Conference on Environment and Development, 1992), Moscow (International Congress on Education and Informatics, 1995) and the aforementioned UNESCO world conferences (1998) have all demonstrated the responsibility which we ourselves, as researchers, feel for the future of mankind. It is this sense of responsibility which tells us that it is us and us alone who can establish the alternatives which this new epoch has to offer as much at a local community level as on a national and continental scale. With this task performed, the responsibility falls to politicians to take notice of our conclusions and warnings.

As one does in one's private life, so communities in the course of their public lives must sometimes stop a while and reflect upon the road they have travelled so far, take a look around and perceive the new challenges and opportunities; only after having done so can they embark upon drawing up plans for the future. This applies to individuals, families and national, social, religious or professional communities alike. As a historian, it seems to me that the ongoing industrial and technological revolution simply forces us, as researchers, to stop and take stock of both the social benefits and drawbacks of what we have achieved so far. In fact, we should also appraise the changes which the scientific and technological revolution has brought and which affect our research activities: changes in the cognitive process as well as in the practical application of research findings (applied research, *angewandte Forschung*), and try at least to formulate questions concerning the future. I personally see it as the objective of this Conference to attempt to clarify:

- the place of science in the new world epoch;
- everything that society and production expects of science;
- the relationship between politics and science;
- the responsibility of researchers.

I hope that the documents of this Conference will credibly reflect the achievement of this objective.

When preparing for this meeting of minds, we all pondered the problems and hypotheses we wished to raise on this occasion. I did too. My questions are along the lines of: What kind of century would I like to see, come the year 2000? How do I conceive of culture, society, the economy and the state in the coming century? And what can science offer to realize our current vision for the future?

Within this framework, please allow me to outline a few thoughts.

Point 1: Cultural diversity

I should like to experience the coming century as one of ethnic and religious diversity where a variety of customs may freely prevail. In addition to the great language cultures – English, Spanish, Arabic, Chinese, French, German, Russian, Japanese and Indian – the cultures of smaller nations should also survive. However, in a world of globalization, the cultures of smaller nations can only survive if they assimilate the high technological and cultural achievements of the world as a whole into their local vernaculars – in other words, if these smaller national cultures, while preserving their traditions, are able to modernize not only their production and social systems but their linguistic culture as well.

The next century will thus be characterized by a double culture. On the one hand, great intermediary languages or lingua franca cultures (among others English, French, German, Russian, Spanish) conveying the most advanced scientific and technological knowledge will become even more important. The local scientific, economic and political elites will learn the intermediary languages to acquire the most up-to-date knowledge. On the other hand, local societies will certainly preserve their vernaculars in their everyday life.

The question – the question of responsibility – is now: what will the local elites use their internationally high-level knowledge for? Will they simply use it to create a socio-economic advantage within the local community or will they also undertake to help these small, local vernacular, national cultures rise to an international level by continually updating the terms, notions and the vocabulary of the vernacular. A precondition for the survival of smaller national cultures is that the national function of science comes into full effect. To my mind, the real threat is not the extinction of these smaller language cultures in the next century, but that they might be reduced to the level of sub-cultures. This also implies that a part of mankind might easily be excluded not only from cultural development but also from social development.

Natural sciences speak of biodiversity, diversity of the natural environment and of the necessity of preserving this biodiversity. Now, I think, the time has come for social scientists to introduce the notion of cultural diversity and set as a requirement the preservation of this cultural diversity.

Point 2: The knowledge-based society and 'open science'

Raising the level of knowledge within societies now living on Earth is a necessary condition for furthering the scientific and technological revolution. Should this condition not be fulfilled, the applications of our inventions would lead to an increasing number of technological and social catastrophes, as well as to a shortage of elite professional manpower. Society may not only promote but also hinder the advancement of science.

We do not dare face the fact that the rate of scientific and technological development has left the level and rate of social development far behind. Raising the level of knowledge is a requirement on a global scale too. What this programme of raising the level of knowledge requires is not only the reform of professional training systems, but also for society to come to realize the so-called daily utility of science. Otherwise we, as researchers, will alienate ourselves from the man in the street who in turn might embark upon organizing anti-science campaigns.

The scientific community, then, should be more open towards society. It should not only struggle against unscientific views. It should not teach society lessons in a haughty manner, but should learn to think together with society. Science in the 21st century must be an open science. Dialogue and thinking together – this is the great imperative of the future to which we have to adhere. For this to happen, however, we have to learn the language of the modern means of conveying scientific knowledge (radio, television, the daily press, etc.) and we also have to learn to write not only scientific papers but scripts for motion pictures as well.

The researcher's *raison d'être* should change accordingly. Attention should be drawn to the fact that in the coming century a researcher will not simply be an inventor, but also a communicator who transmits the world's most advanced scientific achievements and thoughts to society, and who keeps the large scientific and educational 'factories' of local societies in a state of good repair. This means that he is an inventor, an importer of knowledge and a maintenance man all in one. We should also make mention of the fact that we, as researchers, are both globally minded scholars and locally committed citizens. And we are responsible for the level of knowledge and also for the competitiveness of the local society.

Point 3: The relationship between the economy and science

Production offers us, as researchers, not only a clear opportunity for earning money, but it also imparts the challenges of practical life to us as well as to the educational sphere.

Aside from the state and education, multinational companies offer us most of our research and development (R&D) commissions. Indeed, as is widely known, some of them have established their own R&D bases in Hungary. As such, capital will remain one of our main allies well into the next century. But we must realize that capital will always be profit-oriented, so it will only appear as an 'R&D customer'' when the anticipated findings will serve the marketability of the given product. It is only interested in well-defined research topics and only supports particular branches of research. Capital's science-sponsorship activity in the local society is conspicuous only in those fields of R&D which are connected with local companies. It will never be the duty of (foreign) capital to support local science education, innovation or interconnected research topics which follow from one another.

Therefore, we should study the so-called company-level science (research) policy and try to ensure that this company-level science (research) policy balances with the state science policy. Hence it follows that – besides capital – the other ally of the researcher will be the state. But the question remains of what type of state we should like to live in come the next century?

Point 4: The 'serving state' of the coming century

I should like to think of the state in the coming century as a serving one. That is, the state as a local territorial and administrative unit will have to delegate more and more power and economic functions to civil organizations. However, its serving role – over and above its administrative and policing functions and its tasks related to health care and infrastructural development – will have to be extended to encompass education, culture and the support of science.

As far as science is concerned, the state should in part guarantee the freedom of research and the proper conditions for innovation in the local society. The state should be particularly active in those fields where capital is less available. It follows that the state must take care of education and training, professional manpower supply and further training, and must see to it that the institutions necessary for innovation are properly financed, at least to the level of basic provision. And it should also provide for basic research as well as for applied research which is not supported by the business sphere. A consensus needs to be reached between the companies operating within the country and state science policy.

It is not by chance that over the past three years new science policy courses have been adopted by such countries as the USA, France and Germany. The same applies to other smaller states, some of the Far Eastern states, Finland, Austria and also Hungary. The scientific community has to form a new type of alliance with the political elite and to make the latter understand the importance of the state's role in science policy.

Point 5: A new synthesizing approach among researchers

The onslaught of science is a significant phenomenon of 20th century history. It is often mentioned that, of our present-day household articles, the actual 'material' accounts for 20% and the value added, that is 'knowledge', for 80% of the price. Less attention is paid to the question of the extent to which our present organization of research and research culture will be suitable to receive R&D commissions from the user community. While the issues raised by production and society are problem-centred, our science system is discipline-centred. And we fail to draw proper conclusions from the history of science over the past three decades and the fact that the really important discoveries in both the natural and social sciences have taken place in the so-called borderlands of disciplines. Nor do we ask ourselves loudly enough how well our researchers can recognize the user society for which they design fancy machines or wonder weapons. And if they fail to recognize the user society – irrespective of power plants, marvellous edifices, gene technology, chemicals or weapons, either in the Near East or in the Balkan region – will these technical devices fulfil the brief for which they have been constructed? But social researchers should also criticize themselves: how much do they – we – know of the wonderful results science and technology have achieved in the past hundred years? How much are we, social scientists, able to prepare the decision-makers for the wise application of this magnificent storehouse of R&D-based devices? We must admit self-critically that social scientists always concentrate primarily on politico-institutional systems and then on socio-economic changes, and their proficiency in technology, physics, chemistry and biology is frequently far from adequate.

A new synthesizing approach is needed both in the training and in the mindset of researchers, and it is with this in mind that the whole institutional system of higher education and research, including the system of scientific qualifications, has to be revised.

As a historian, I may perhaps add one more observation on this topic: just as the first half of this century saw breakthroughs in physics, so the following decades witnessed great advancements in chemistry then in biology and, just as our immediate past has been the age of the development of informatics, so the scientific and technological revolution will now offer a big challenge to social sciences. In order to formulate this new synthesizing approach to scientific matters we need encouragement and, primarily, progress from scientists.

I trust that during your stay in Budapest you will be able to enjoy not only the scientific discussions but the beauty of this city as well. I hope that you will feel at home here and will take with you pleasant memories when you leave. And lastly, I hope that this Conference will offer you a good opportunity for making personal contacts. We should remember that neither the cognitive process nor the so-called international contacts of science can do without the human factor. In other words: without the 'software' of the human personality, of the human soul, the human spirit, the 'hardware' of science will never function.

In hoc signo, have a nice week in Budapest.

Opening address

Pál Pataki

Chairman, Executive Board, UNESCO

The delegates meeting at the Institute of Civil Engineers in London on 1 November 1945 had been invited to the founding Conference of the United Nations Organization for Education and Culture, UNECO. Several scientists, however, including Julian Huxley, who was to become the first Director-General, had been campaigning for months for the inclusion of science both in the name of the new organization and in its programme of action. The President of the Conference, Ellen Wilkinson, Minister of Education of the UK, proposed in her inaugural address than an 'S' be inserted between the 'E' of the education and the 'C' of culture.

'In these days,' she said 'when we are all wondering, perhaps apprehensively, what the scientists will do to us next, it is important that they should be linked closely with the humanities and should feel that they have a responsibility to mankind for the result of their labours'.

On 6 November 1945, the Conference of London decided to add the 'S' of science to the acronym of the organization, which thus became UNESCO.

The apprehension felt some 54 years ago is still with us today as I welcome you, on behalf of UNESCO's Executive Board, to the World Conference on Science, during which scientists and policy-makers will reflect together on the major issues of science and society with the aim of establishing some kind of contract between the two.

In the dazzling glare of the latest achievements in the sciences, it is time to pause awhile to ask ourselves questions and together seek the answers to them. We are gradually gauging the extent to which scientific and technological developments are endowing humankind with the power to act upon the planet and the universe, on the very processes of life.

We realize that this power may set off irreversible chain reactions. Science, which was long regarded as an odyssey of knowledge, has become an action-oriented undertaking. Whether we are bystanders or active participants, it is increasingly clear to us that, wherever we may be, we are living in an ever more interdependent world.

As we watch the vertiginous progress of science, we note at the same time the emergence of a strange phenomenon, or should I say the revival of one that was long forgotten: the return of the secret sciences and their inherent dangers.

The great ambition of the Renaissance was to open the secret box of knowledge and render the sciences accessible to everyone; and indeed science did become public property.

But today it is as if the seal of secrecy was back once more! In scientific research the attraction of the market place is growing constantly stronger and so the findings of research financed by the private sector are patented and no longer circulated. How can we reconcile protection of intellectual property rights with free access to knowledge? How are we to safeguard the principle of open science? How are we to guarantee the sharing of knowledge? The world has need of your answers.

There is no doubt that something radically new has happened in the last quarter of the 20th century. A veritable paradigm shift has occurred as a result of a combination of various sciences issuing warnings on the hazards and dangers to which our environment is subject. Today environmental issues have become part of the daily political life of our societies. Over and above a somewhat 'romantic' appreciation of the beauty of nature, we are slowly but surely recognizing that 'business as usual' will not do, lest the environment rapidly become a security issue.

Dwindling resources and growing population are indeed a large question mark over the concept of sustainability, or perhaps survivability. Bad land management practices, marine pollution and the looming freshwater crisis are all signs that unless environmental issues are addressed with a more coherent political will, and more coherent scientific enquiry too, humanity may have difficulties in surviving the next century. We will simply drown in our waste.

I am convinced, and think you would all agree, that global and national environmental programmes need to be significantly strengthened.

Without the help of science, policy-makers will be unable to strike the necessary balance between the often-conflicting goals of economic growth, social equity and the protection of the Earth's resources and life support systems. How can this balance be struck? The whole world is in need of your advice.

Au cours de la Conférence de Londres en 1945 les pères fondateurs ont doté l'UNESCO d'un Acte constitutif qui n’a rien perdu de son actualité. Partant du constat que « les guerres prenant naissance dans l’esprit des hommes, c’est dans l’esprit des hommes que doivent être élevées les défenses de la paix », ils ont créé une organisation de coopération intellectuelle, préconisant l’idéal d’une chance égale d’éducation pour tous, la diffusion de la culture, l’avancement et la diffusion du savoir, la libre circulation des idées.

Les impératifs n’ont pas changé, cependant les chemins de la coopération ont connu de profondes transformations. Les réseaux des ordinateurs, les autoroutes de l’information nous permettent de mener des dialogues constants comme si nous étions assis autour de la même table. De toute évidence, cela a transformé complètement les méthodes de recherches scientifiques, les mécanismes d’échange entre les scientifiques. Et cela ne manquera pas de transformer profondément l’UNESCO.

François Rabelais a écrit en 1532 la fameuse lettre de Gargantua, dans laquelle celui-ci encourage son fils Pantagruel, étudiant à Paris, à profiter pleinement des moyens nouveaux permettant aux jeunes d’enrichir leur culture. Rabelais emploie dans cette lettre une admirable formule: « Science sans conscience n’est que ruine de l’âme ».

C’est Science avec conscience que je mettrai en épigraphe de cette Conférence mondiale qui, comme je l’espère, formulera des engagements limpides :

- l’engagement des décideurs à adopter des politiques nationales qui prévoient un appui soutenu à la recherche scientifique et qui favorisent le partage et le transfert des connaissances ;
- l’engagement éthique de la communauté scientifique, un engagement qui souligne le devoir de vérité, l’obligation d’oeuvrer, dans le respect des droits de l’homme, en faveur du bien-être de l’humanité.

Opening address

Werner Arber

President, ICSU

The partnership between UNESCO and the International Council for Science, ICSU, in the organization of the World Conference on Science represents a highlight in the long history of collaboration between our two organizations. In recent years, particular emphasis has thereby been given to interdisciplinary research programmes on environmental issues such as global change and biodiversity.

Let me say a few words on the structure and function of ICSU. The International Council for Science is a worldwide, non-governmental organization of scientists. Membership is of two types, based on either scientific disciplines or on geographical and political criteria. The 99 national or regional members of ICSU are often academies of science or other interdisciplinary associations. The 49 full or associate disciplinary members of ICSU are often international scientific unions. The represented disciplines encompass all the natural sciences and range from mathematics and astronomy to specialized fields in the life sciences and include, of course, physics, chemistry and the earth sciences. Please note that this roughly corresponds to the definition given to science in the context of our World Conference on Science. Most of what is commonly understood under humanities, social sciences, clinical medicine and engineering is thus not part of our debate on science per se, although some important segments of these fields of knowledge are essential in the evaluation of the impact of science and its applications on society.

While we can assume that UNESCO represents practically the entire world population of 6 billion people, it is more difficult to quantify the number of scientists represented by ICSU. My rough estimate comes to perhaps 3-10 million active scientists worldwide, which corresponds to about one per mill of the human population on Earth. In some highly developed countries, about 1% of the population is actively engaged in scientific activities; in less developed countries it is considerably less, sometimes only a fraction of a per mill. Nevertheless the impact of science on our civilizations is considerable and worth an intensive debate during the next few days.

Doing science means trying to understand nature and its laws. The objects of our studies are matter, its components and the interactions between these components. A major part of this matter is inanimate, while a smaller part exerts life, to which life sciences pay particular attention. As far as we know, the basic properties of matter and most properties of life are the same anywhere on our planet and perhaps throughout the universe. It is for this simple reason that most scientific investigators communicate intensively with each other on a global scale. Personal relations thereby develop on the basis of the recognized quality of the scientific knowledge exchanged. Scientific communication across political borders is an excellent contribution to the peaceful development of our world and this deserves better recognition. Besides its contribution to peace, science is also an important source of cultural values which reside in the acquired knowledge. As far as we know, it is the unique privilege of human beings to explore nature and to exchange and store the acquired knowledge as a heritage for future generations. This is at the centre of UNESCO's aims and ICSU is glad to be able to foster these activities.

A critical view of human nature can reveal a duality formed by a trend towards a conservative attitude and an open mind to benefits from progress. It is in this context that the general public manifests a degree of anxiety towards some of the technological advances based on newly acquired scientific knowledge. Carefully carried out, technology assessment, as well as policy assessment, can help to guide society towards safe development. ICSU and its member associations have frequently been engaged in advising politicians on the basis of advanced knowledge and they are willing to intensify these activities. However, we must be aware that, by a long way, not all developments occurring in nature are fully reproducible or precisely predictable. This has to do with the complexity which underlies many of the processes forming the basis not only of life but also of the inanimate world. I consider it an important duty of us scientists to remind the general public that we do not live in a fully domesticated world but rather in a world with inbuilt uncertainties and a world on which we can, in many cases, have no influence.

Let me illustrate what I have just said by referring to some findings of molecular genetics, the field of my own research activities. Genomics and proteomics are recently introduced terms to characterize those fields of science which investigate the structure and function of genes and the main gene products, the proteins, respectively, which can be considered as mediators of life activities. While for some biological functions both reliability and reproducibility in the catalysed reactions is essential and is indeed obtained, this is not the case for some other functions. In these cases, nature takes it as a privilege to exert flexibility, which offers a tremendous potential for development. This plays, for example, a central role in biological evolution. Accumulated knowledge in microbial genetics provides compelling evidence that a good number of microbial genes act as generators of genetic variation, thereby increasing the chance that microbial populations can adapt to changing environmental conditions. These observations imply that the same carrier of inheritable information has also, besides the genes for biological functions for the benefit of each individual, genes whose functions are to the benefit of the evolution of the population. It remains to be seen how general this concept of nature is to actively care for the evolution of life. Interestingly, generators of genetic variation do not a priori determine the direction of evolution, this is accomplished rather by natural selection, i.e. by the environment in which the organisms live.

The lesson to be learned from this recently acquired knowledge is likely to become of great importance in the next century. Generally stated it says that the life of each individual, as well as the long-term biological evolution of life, depends on functional genes, but that many of these genes may not act as genetic determinants in the strict sense of the word. Rather, many genes influence life processes in tight collaboration with other, often external factors, such as environmental conditions, chance events, but also intrinsic structural flexibilities of biomolecules. I see in these insights great philosophical values which are likely to influence the world view of future generations and which may also enrich our potential to use more responsibly the limited natural resources for the benefit of mankind.

Science is a gateway to an immense source of knowledge. The acquired knowledge opens rich possibilities for applications to improve human life conditions. These applications range from technological progress deep into the steady adjustment of our conceptual understanding of the world in which we live. More and more, human society will become aware that its future does not uniquely depend on the well-being of man, but also on the well-being of man’s environment, the living and inanimate surroundings offering the essential substrate for our lives. This insight will guide us from a still prevailing, largely anthropocentric view to a more holistic one, according to which we are a small though important part of this wonderful world, the development of which is based on deeply anchored interdependences.

To finish, let me express the hope that the views which I have just tried to summarize can provide us with guidance through intensive, deepening debates during the next few days. I would like to express my sincere thanks to all those who have helped in the preparation of the Conference and who will, by their active participation, contribute to the outcome of the Conference. Very warm personal thanks go to our Hungarian hosts and, in the name of ICSU, to UNESCO for its proposal to join forces for a discussion on science and its impacts at the turn of this millennium.

Opening address

Federico Mayor
Director-General, UNESCO

I am delighted to be witnessing the opening here today of a World Conference in which we place high hopes. Allow me to emphasize how much the stakes, of which we are all aware, are raised by the symbolic fact that we are about to enter a new century and a new millennium. This impending event is sharpening our sense of responsibility.

I am pleased, first of all, to express my gratitude to His Excellency the President of the Republic of Hungary and his Government for their generous hospitality, the efficiency of their preparations and the accessibility of their representatives. We are glad that Hungary has for so long been providing the international scientific community with brilliant researchers whose works have been granted the highest distinctions.

I should also like to express my satisfaction that this Conference has been organized in partnership with ICSU, the International Council for Science, which has long been one of UNESCO's most important allies, and in collaboration with other international organizations. I wish to extend a warm welcome to all the participants, the representatives of states and intergovernmental and international non-governmental organizations, as well as to the representatives of the media and of all segments of society.

With our work about to begin, I should like to stress that we are inaugurating a new type of conference here today. Unless I am mistaken, it is the first time that not only the specialists and decision-makers but all the other actors of contemporary science, including the social sciences, have come together around the same table. The questions of science – the questions which it raises, which it asks itself and which are asked of it – made it high time for society as a whole to join in the debate. I am convinced that this innovation will help to make the discussions more relevant and add to the effectiveness of the action which will follow.

We are here in Budapest to map a course for science in the years and decades to come. Mapping has been one of the most universally shared human activities across the ages. From the most rudimentary diagrams marked in sand or clay, to the mapping of the human genome, it has been fundamental to the organization of knowledge and to the planning of journeys. Here, we will try to map a new future for science. Now, maps are never entirely neutral. They reflect standpoints, are organized around a chosen centre and according to selected criteria. Who makes the map, how it is made and what it charts are therefore of paramount importance.

You, the participants in this Conference, offering a combination of talents and representing a range of stakeholders, will give this collective mapping process the legitimacy it requires. What should feature on our map? I will give you my priorities: science for development, to uplift human dignity everywhere, science for peace and democracy-building, science with women, science in the community, science offering the solutions that our society and our planet so urgently need.

I wish now to address in particular the many government representatives present here. And – if you will permit me to continue a little longer with the same metaphor – I must point out that a map has to take into account the traveller's means of transport. What means do we have at our disposal for science's journey into a new future? Are we to travel on foot, by horse and cart or by jet plane? The scale of our map depends first and foremost on you. It depends on government commitment translated concretely into a percentage of national budgets. It depends on the overseas development aid commitment of the industrialized nations. This direct, public support is the lifeblood of basic research and of all levels of science education. Make no mistake: science needs political will. It needs funding and structured support and, in return, it must respond to the needs of society.

There is another point I would like to make very clear. A government's responsibility is not over when it has set aside a budget percentage for science. Reflect for a moment on the implications for government policy-makers of the pace of scientific advances. The world as we now understand it through science differs more dramatically from the world of Pasteur than the science of Copernicus and Newton differed from Aristotle's. And reflect on the context: the world today is marked by such rapid change, such complex problems, such a variety of interactions – and of actors – that we cannot just set funding levels and leave science to 'get on with it'.

We need a financial commitment that reflects an equally resolute political commitment, with both translated into strong research policy. Science is too important to be left to the markets. As for so many other areas of human activity, democracy – active, participatory democracy –is a key part of the solutions we are seeking.

Let us work out together how to forge a new relationship between science and society, harnessing the powerful resources of the private sector and the public sector, setting sustainable development goals, bridging the knowledge gap through capacity-building and knowledge transfer, not just North-South but also South-South, stepping up efforts to communicate science and – last but not least – facing the tough ethical questions to which public opinion quite rightly demands we pay proper attention.

There must be no glossing over the issues here in Budapest. Our task is not to rally support to the most easily acceptable aspects of science, avoiding the problems raised by advances in biology or by the control and ownership of scientific assets. This is not the time for any of us to throw up our hands and say, ‘You can’t stop science’, or ‘You can’t interfere with market forces’. To paraphrase a remark of Jacob Bronowski, defining the uniqueness of humankind: we are not figures in the landscape, but shapers of the landscape. Well, let us make sure that is really so. Technophobia, in my opinion, is triggered by a perception that runaway science and technology have become the shapers of the landscape, reducing us to mere figures. The new relationship between science and society must prove that this is not the case. It is up to us – all of us – to shape the landscape, with government policy-makers, public and private research institutions, international government organizations and non-governmental organizations working together to define the goals and the roles, reaching out, through networks and new forms of collaboration, through associations for the advancement of science. The dynamic, participatory nature of this process of transformation requires each and every stakeholder to play a part. UNESCO is fully aware of its own responsibilities in this process.

The founders of our organization could not foresee what extraordinary developments would occur in science and in the world when they defined UNESCO’s roles. But they could not have made a more propitious choice than when they gave the ‘intellectual arm’ of the United Nations system a specific responsibility for science. Then, at the end of the 1940s, IUCN–The World Conservation Union was born and, later on, CERN, the European Laboratory for Particle Physics, and the International Geological Correlation Programme; then we had the Man and Biosphere Programme, the International Hydrological Programme, the Intergovernmental Oceanographic Commission, the Management of Social Transformations programme, the Biotechnology Action Council and the Global Network for Molecular and Cell Biology.

Half a century later, we are only now beginning to see just how global scientific research has to be; just how global, the most crucial problems requiring science-based solutions; just how global, the successful approach, the relevant ethical principles, the adequate solutions: solutions we are seeking jointly with ICSU, academic institutions, university associations.

And we have UNESCO: a global body – globally representative, running unique worldwide scientific programmes ranging from a global ocean observing system to microbial research and education networks, offering a global framework for the ethical review process, a global clearing house for best practice in science education and communication. I pledge that we at UNESCO will do everything in our power to put all this experience, which is your experience, all our capacities, which are your capacities, to work. We are here in Budapest to make a new commitment: this is our new commitment: to interact more; to address global matters in all their complexity, without trying to simplify them; to offer decision-makers timely advice.

On the threshold of a new century and a new millennium, we are confronted with a range of tendencies and dangers which are increasingly interdependent, and which require all-round responses from society as a whole and not only from one specialized sector. Complexity and democracy are, therefore, two sides of the same nascent reality: the reality which is just coming into view and which compels us to ensure peace, consolidate democracy and promote endogenous and sustainable development. Solutions are always to be found within; within our own selves and within countries.

One of the fundamental characteristics of the new century will no doubt be the close link between scientific criteria and political decisions. For an effective response to be given to the new challenges, the politicians will have to listen and take scientific criteria into account; at the same time, the scientific community must have enough support for society, expressed in the form of democratic participation in the institutions. All political leaders are responsible, but those who wield most power also bear most responsibility. Three conditions have to be met for this symbiosis between science and the authorities to bear all its fruit: democratic participation, medium- and long-term forecasting, and the capacity to share knowledge and resources, responsibility and hope. As our world society becomes more and more numerous and diverse, the links between the need to share, the possibility of participation and the capacity of prevention are becoming increasingly obvious. But prevention and anticipation usually go unnoticed when they are successful, hence much of our work consists in an investment in intangible social factors.

The science of the new century will be a more dynamic activity which, above all, will be conducted on a world scale. The acquisition, transmission and application of knowledge have been transformed by the speed of communications, by the possibility of accessing libraries and the most advanced research centres from any part of the world using electronic media, and by an awareness of the social impact of scientific and technological advances. But the very speed of technological advance, in the midst of the inequalities and imbalances from which the present world suffers, threatens to destroy the moral framework and imperil the future of civilization. The Spanish poet, Antonio Machado, wrote a line of verse which I usually quote in this connection: ‘It is foolish to confuse value and price’. We scientists have the duty of clearly enunciating the values which make up the ethical framework of our world. The constitution of UNESCO warns us that economic development is necessary but not sufficient; and that political development is necessary, but not enough. It adds that peace and welfare are based on ‘the intellectual and moral solidarity of mankind’. This same mission of intellectual and moral solidarity is what should guide scientific development in the new century if its results are really intended to contribute to the achievement of liberty and dignity for all.

Budapest is not divided by a river. Buda and Pest are joined together by a river, the Danube, which we fondly imagine to be blue. Hungary has experienced the splendour of an empire and the bitter obscurity of oppression and silence. We all have a duty to remember, but Hungarians – because of their deep roots as well as their more recent branches – remember vividly each day the value of liberty and the indomitable rigour of the spirit.

All we can do with the past is to record it. It remains as it was. And we must bear this in mind, learning the lesson of what should not be repeated. But we can and should write the future together. We have a duty to remember the future, which is intact before us. We scientists will not remain silent. Joining hands with all the other sectors, we shall not stop writing the future and we must do it differently. The use of force and imposition has failed resoundingly. And at what price! The price of millions and millions of human lives. Immense suffering. Indescribable perversities. We have discovered antibiotics, how to communicate, the most sophisticated surgical techniques; but we have not managed to ensure that dialogue and tolerance prevail over the law of the jungle; we have not succeeded in blending knowledge sufficiently with wisdom. On the threshold of the 21st century, the sciences (natural, social and human sciences), meeting in harmony in Budapest, proclaim to the world from the heart of Europe that they will contribute to the transition from the logic of force to the force of reason, from the culture of war of times past to the culture of those who offer our children the fruits of love for a new age.

KEYNOTE SPEECH

Science for the 21st century

José Israel Vargas
President, Third World Academy of Sciences

Let me first warmly thank UNESCO and ICSU for the invitation extended to me to take the floor at the opening ceremony of this Conference and address it on behalf of the Third World Academy of Sciences, over which I have the honour to preside. I am aware that this distinction is a tribute to the many colleagues of our generation who, in the developing countries, under the pressure of necessity, after training and often working abroad, have been summoned to an early assumption of responsibilities in science and technology development, over many years, in their own countries and sometimes in the international arena. I am sure that this tribute would be particularly fitting for my predecessor and founding father of our Academy, the late most distinguished scientist and international personality, Abdus Salam – one of the great flagbearers of science. First and foremost, he thought that basic sciences should receive special attention, for there is no applied science – i.e. technology – without science.

Ladies and gentlemen, allow me to recall that we are assembled here on the threshold of a new millennium to ponder the pressing demands for launching a new social contract under the aegis of science, bearing in mind at the same time the recollection, not only of the upheavals and pangs that science has mainly entailed in this terrible century of ours, but also of the splendid enlightenment it has brought about, enlarging and deepening our understanding of the workings both of nature and of the very fabric of society.

A new social contract for and with science and technology as a lever for improving the lot of the species does also, of course, remind us of an analogous contract, first enshrined here in Europe two centuries ago. According to John Burnett – as cited by Schrödinger – this quest of science for rational enquiry is deeply rooted in ancient Greece. For him ‘it is an adequate description of science to say that it is thinking about the world in the Greek way’, a vision that along the last centuries has steadily shaped our world.

The pursuit of happiness and the happiness of pursuit, according to Albert Hirschman, are equally fundamental human aspirations that the new contract we are now supposed to search for must not forgo, in spite of the infinitely more complex and daunting context of the present age. In fact this last aspiration is the main source that moves the first pursuit, for science should, so as to say, be placed at the service of happiness, to encompass the knowledge not only of humanity, but also of nature as a whole.

The pursuit and achievement of science and of technology – which is intrinsically more and more ancillary to science – has contributed powerfully, via growing energy production and utilization, to diminishing human toil; it has improved health and increased the span of human life; through progress in transportation and communication, it has fostered the mutual knowledge of individuals and of cultures – millions of human beings cross national borders every day and hundreds of millions of written, visual and sound messages are exchanged almost instantaneously, all around the world.

We rejoice, as we indeed should, at these many blessings of science. However, these high-sounding claims should not divert us from the awareness of the terribly dire consequences of the inconsiderate use that society has made of science and technology throughout history, in war and in peace. Most of the time, the social contract we are referring to has been broken – as has been abundantly demonstrated in this part of the world, where the pursuit of collective happiness was ultimately doomed by the sacrifice of the right to the pursuit of happiness by the individual. And so, the fruits of the happiness of pursuit have indeed met with much more success than those born from the pursuit of happiness.

Firstly, the fruits of science and technology have not significantly benefited the majority of human beings living in the Third World. The asymmetry in the distribution of wealth, of safety and of comfort has, in fact, increased in recent times, as testified by the 1998 United Nations Human Development Report. ‘Some 80% of the world’s people live in the Third World countries but they have just 22% of the world’s wealth. The poorest fifth of the world’s nations held 2.3% of the world’s riches 30 years ago; today they possess exactly 1.4%. In more concrete terms, the assets of the three richest individuals in the world exceed the combined GNPs of the 48 least developed countries; some 358 global billionaires have wealth equal to the combined incomes of the world's 2.2 billion poor people, that is, nearly half of the global population.' And more: 'of some 4.4 billion people in the Third World – still characterized as developing countries by the United Nations, even though most of them have not been developing at all – three-fifths lack access to safe sewers, two-thirds lack toilets, one third have no access to clean water and a fifth lack any kind of modern health care. About one quarter of Third World people are illiterate'. A new social contract conducive to peace must as of necessity squarely face and tackle this situation with all intent and determination to start solving these unbearable misfortunes. In all fairness, the richest countries of the world have just decided to forgo about one-third of the debt incurred by the poorest ones with the international finance and government institutions. Although this decision is in the right direction, far more must be done.

Secondly, the growing adverse impact on nature resulting from human actions in the exploitation and transformation of natural resources may severely compromise our life-sustaining systems on a global scale, to the detriment of future generations. Of particular concern is the warming of the planet by the greenhouse effect resulting from human actions, mostly taking place in the industrialized countries.

Thirdly, the new information and communication technologies, despite their immense potential to deal with developmental issues for the dissemination of culture and education, are bringing forth new risks affecting not only fundamental individual rights such as the right to privacy, but also the safety of trade and even national security itself in the face of a growing potential for war: the cyber war.

This baffling picture is further reinforced when consideration is given to the potentially harmful consequences, for both individuals and for society's very texture, arising from the new findings in biology, particularly those bearing on genetic manipulations. Besides some risks and uncertainties related to these new applications of science, scientists of the Third World are deeply concerned about the proprietary aspects of genetically modified seeds, which conflict with the millennial rights of farmers to keep their seeds. It has to be stated that life forms belong to all of humanity and are not patentable entities.

While these risks may affect us all, they do so asymmetrically for, again, it is the poorest sections of our society, both at the national and at the global levels in the economically underdeveloped regions, that bear the brunt of these inconvenient facets of progress.

Admittedly, risks do also create immensely useful new opportunities for the developing world. So, there is hope and scope for actions.

On the international scene, the reversion of the traditional North-South flow of scientific information as a core aspect of the ever-increasing number of cooperative research projects calls for immediate action. In fact, the need for Northern scientists to work closely with their counterparts in the South constitutes an important part of an intricate chain to advance problem-solving scientific research on a global scale – moving, for instance, from global climate change, biodiversity conservation and utilization, to geographically distributed research equipment on astrophysics to support large-scale operations. This approach would for example extend the ongoing cooperation of scientists from the South with international laboratories such as the European Laboratory for Particle Physics (CERN), the Fermilab and the International Space Station, dealing mainly with fundamental big science physics problems.

The need for South-South cooperation stems from the sharing of many concerns related to science, technology and development by Third World countries, despite the differences in their geography, culture and economy. Many of them, which are arid, semi-arid or tropical, also share problems resulting from their biogeographical similarities over and above their geopolitical locations. Some of these problems could be tackled, for instance, by the utilization of modern space technology. Brazilian, Indian and Chinese data-collecting and remote-sensing satellites could address down-to-earth concerns: changes of temperature, humidity, carbon dioxide concentration in the atmosphere and real-time data on alterations in soil and water quality, which are important for the examination of critical environmental problems, are also of great social and economic importance for many other developing countries. Brazil has in fact offered the use of its satellites and data-collecting platforms to African countries through UNESCO. Ultimately, the entire scientific community, both in the North and in the South, reaps benefits likely to accrue from using scientific data and knowledge to solve real problems faced by real people, especially the two-thirds of the world's population – some 4 billion people – living in the developing world.

Another approach worth exploring is the establishment, by scientists from the South, with the cooperation of their colleagues from the North, of networks devoted to the solution of pressing concrete science-based problems. The present Third World Network of Scientific Organizations, TWNSO, could, in collaboration with ICSU, set the pace for such initiatives.

Culture and languages in their diversity constitute an essential and rich component of humanity's heritage, but they are also barriers to communication and mutual understanding among peoples. The project to allow the on-line translation in real time via the Internet of different languages opens the way to overcome these barriers and offers a most extraordinary opportunity for the effective creation of a world virtual university, in fact for the development of virtual education at large, accessible to millions of individuals all over the world.

This project – Universal Networking Language – presently involving scientists of 15 countries under the leadership of the United Nations University Institute for Advanced Studies in Tokyo, is most exciting and constitutes perhaps the greatest contribution that information science may offer to peace, overcoming the Tower of Babel syndrome, while at the same time preserving the linguistic diversity of cultures.

In fact, education at all levels is present, as it certainly should be, in every single agenda item of our meeting and I shall not therefore dwell on it further.

The immense task of overcoming this dramatic situation demands also the appropriation by all of the accumulated experience of those countries that have lately emerged to industrialization. One should however bear in mind that developing countries comprise an extremely diverse ensemble and that no single prescription for development is valid for most of them.

Although industrialization in itself should be a desirable goal to be eventually attained, the choice of the development route, as pointed out before, should take into account not only the social and cultural environment, but also the physical local production factors.

However, it is to be emphasized that underdevelopment should not be comprehended as an early stage of the industrialization process. The industrialization route observed by developed countries during the last two centuries, from the Industrial Revolution on, in practice, is really not reproducible in the developing countries. Late-industrialized countries, like Brazil and others, must credit their own relative success, on the one hand, to the massive access to, and transfer of, technology made possible by the political use of the many power disputes which characterized this last century – with its two World Wars and a long-lasting Cold War – and most significantly, on the other hand, to a concomitant comprehensive science education policy. In the last 50 years the Brazilian university population has, for instance, been multiplied by a factor of 34, leading to a considerable expansion of scientific production and to important technological developments in some key areas. Furthermore, it should be recalled that part of the success must be credited also to various tariff barriers and secluded market reserves. Such a policy seems manifestly most doubtful in the present globalized liberal world and is certainly not sustainable for those nations that have not yet succeeded in attaining a certain level of development, unless new major policy initiatives are adopted for their benefit.

One should bear in mind, in agreement with the more helpful considerations expressed by Surendra J. Patel, that during the three decades which are considered the ‘Golden Age’ of the South’s development (1950-80), the South as a whole with its over 140 states and 4 billion people bettered the 80-year record of the North’s 19th-century advance (1820-1900). The South did this in half the time, at twice the growth rates and with six to seven times (on average) the North’s population. So according to Patel, ‘no matter how severe the current crisis, it is good not to forget these monumental achievements. The lessons of this rich experience need to be distilled’. This may help to forge future strategies for overcoming the past weaknesses and building confidence on its strengths.

Admittedly, these new strategies will depend heavily on finding a successful solution for the present anarchic situation prevailing in the world’s financial system, dealing necessarily with a new definition of the roles and functioning of the World Bank and the International Monetary Fund (IMF). Indeed, the recent financial crisis that has affected some major emerging nations may, for instance, entail a 2-3% reduction in their gross national products (GNPs). If this is in fact to happen, 3 million people would cross the poverty line in Brazil alone. It would also lead to a reduction in GNP of about US$ 25 billion, which represents more than double the total current yearly science and technology expenses of my home country.

The approach that will lead to any meaningful success in facing the disparities among nations must, in addition, put a stop to the accelerated reduction of international development aid, now amounting to a mere 0.25% of the industrialized countries’ GNP. This corresponds to US$ 30 billion. In fact, in the 1990s alone, international aid was reduced by 40%. The re-establishment of these funds should support science development in Third World countries, in addition to their own national efforts.

One should strive to avoid this Conference repeating the frustration in reaching its goals that happened with the Vienna United Nations Conference on Science and Technology for Development, on which many of us present here today placed extremely high hopes 20 years ago. First of all, one should realize that the overall state of the developing world is worse today than it was in 1979.

The new social contract shall only prevail if these factors, among many others that make up the present world scenario, are faced with courage and determination by our societies through a reinforced United Nations' system, the non-governmental organizations and the organized efforts of the world scientific communities. I am sure that organizations like TWAS and TWNSO, together with ICSU, have an important role to play, making an outstanding contribution to this new commitment.

Bertrand Russell, one of the intellectual giants of the 20th century, has told us that his thoughts and actions were profoundly influenced by the content of Emmanuel Kant's epitaph, which refers to the two wonders of life, the starry heavens above our heads and the moral law within our hearts. The new social contract that is being discussed here shall transcend the new millennium only if the fruits of star-gazing, fulfilling the right of the happiness of pursuit, go together with the commitment, within our hearts, to the moral law in our pursuit of happiness.

This should be our pledge in this new contract.

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KEYNOTE SPEECH

Science in response to basic human needs

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Basic human needs: a 20th century balance sheet

Poverty and social and gender inequity are increasing globally and nationally. According to the World Bank, 1.2 billion people lived on less than US$ 1 per day in 1987. This number increased to 1.3 billion in 1993. About 3 billion people worldwide lived on less than US$ 2 per day in 1993. Nearly 1.5 billion of the world population of 6 billion will live in severe poverty at the dawn of the new millennium. The gap between the rich and the poor is increasing day by day, with disastrous consequences for achieving the United Nations goal of reducing poverty by half by 2015. Achieving the Food and Agriculture Organization of the United Nations' (FAO's) World Food Summit goal of reducing the number of children, women and men going to bed hungry by half from the present number of over 800 million by 2015 may also not be achieved, since hunger today is essentially poverty induced. In addition to energy-protein under- and mal-nutrition, over 2 billion suffer from micronutrient deficiencies.

Global per capita water supplies are declining and are now 30% lower than they were 25 years ago. By 2050, as much as 42% of the world's population will live in countries with insufficient freshwater stocks to meet the combined needs of agriculture, industry and domestic use. In addition, water is needed for the maintenance of ecosystems. Water conflicts are likely to grow. Hence, a Committee chaired by me has recommended the establishment of an International Centre for Cooperation in Water Management at Valencia in Spain, in order to initiate proactive action in resolving potential water conflicts.

Contaminated drinking water causes diseases that account for 10% of the total burden of disease in developing countries. Also in 1996, about 1.4 billion low-income and over 400 million middle-income people lacked access to sanitary facilities. At the present rate of progress, over 900 million persons will lack adequate sanitation in the year 2015. In one out of four major cities surveyed by the United Nations organization Habitat, fewer than 10% of households had sewerage connections.

The International Conference on Health Research for Development planned for the year 2000 should accord priority to developing an implementable strategy for reaching the unreached in the health sector.

Disparities are also growing in access to technology. For example, 97% of all Internet hosts are in developed nations, home to 16% of the world's population. The rapid expansion of proprietary science covered by intellectual property rights is leading to the emergence of 'technological apartheid' and to 'orphans remaining orphans' in relation to the choice of research areas for priority attention. Support from public funds for research aimed at public good is tending to decline.

The coming century is being referred to as a 'knowledge century', a century of innovation, enterprise, eco-entrepreneurship and genetic enhancement. Yet, UNESCO's goal of literacy for all is still a far cry in many developing nations. Enrolments by female students are catching up with those of boys in some regions but continue to lag in others. Intensive efforts have, however, significantly increased primary school enrolments during the 1990s. In India, an innovative Education Guarantee Scheme was first introduced a few years ago in the state of Madhya Pradesh. This approach is now being extended to the entire country in order to accelerate progress in achieving the goal of total literacy. However, in many countries of the Middle East, North Africa, South Asia and sub-Saharan Africa, girls' enrolments continue to lag behind boys' and illiteracy rates are still high.

It is not only in opportunities for education that children of many developing countries remain handicapped but, even more alarmingly, in opportunities for the full expression of their innate genetic potential for physical and mental development. For example, 25-50% of children born in several developing countries are characterized by low birth weight (LBW), caused by maternal and foetal under- and malnutrition. The United Nations Commission on Nutrition in its recent report (1999) has warned about the serious consequences of LBW for both brain development in the child as well as the health of the child in his/her later life.

The rich-poor economic and technological divide is not only causing inequity at the level of the present generation, but is also enhancing inter-generational inequity. For example, Panayotou *et al*. (1999) point out that the affluent economies of the temperate zone are likely to impose severe net costs on the tropical regions because of their excessive consumption of fossil fuels leading to a large release of greenhouse gases. Since the temperate-zone economies are rich and the tropical-zone economies tend to be poor, global climate change represents a burden imposed on the poorer countries by the richer nations.

Panayotou *et al*. (1999) also point out that much of the damage caused by a continuous rise in carbon dioxide (CO_2) concentrations in the atmosphere will occur in tropical countries, especially Africa and India. India and countries in Africa are predicted to suffer adverse agricultural consequences, possibly severe vector-borne diseases, increased risks of severe tropical storms, vulnerability to rising ocean levels and other stresses from an increase in temperature from already high levels. The temperate zone countries are either little affected in general or may even benefit on average by the prospects of global climate change. Agricultural productivity is predicted to rise in the high latitudes, through a combination of longer growing seasons plus CO_2 fertilization of crops.

Thus, affluence as well as poverty-induced environmental damage leads to multiple forms of inequity, namely, inequity at birth in mental capacity, inequity in opportunities for a productive and healthy adult life, and intergenerational inequity.

Among the more serious dangers to sustainable human development is the increasing damage to our basic life-support systems comprising land, water, flora, fauna, forests, the oceans and the atmosphere. The number of environmental refugees is increasing day by day due to damage to environmental capital stocks resulting in the loss of rural livelihoods (Myers and Kent, 1995).

The various United Nations conferences held during this decade have led to global plans of action which, if implemented, could lead to a better life for all. The conventions on climate, biodiversity and desertification, the Law of the Sea and Agenda 21 of the United Nations Conference on Environment and Development (UNCED) provide a framework for the sustainable and equitable management of nature and natural resources.

In my view, the World Food Programme (WFP), FAO, the United Nations Children's Fund (UNICEF), the World Health Organization (WHO) and the United Nations Development Programme (UNDP) should immediately launch in collaboration with interested national governments a global programme to fight maternal and foetal undernutrition, thereby helping to minimize the frequency of children with low birth weights. The programme may be entitled Global Movement for Children for Happiness. A similar programme involving horticultural and direct intervention approaches needs to be launched to eliminate hidden hunger caused by the deficiency of micronutrients in the diet. Without these two steps, the foundation for achieving the goals of the United Nations conferences listed above cannot be laid. Millions of children will continue to be born for mere existence and not for happiness if this area of nutrition continues to receive inadequate priority. This is why the proposed WFP-FAO-UNICEF-WHO-UNDP initiative for fighting the incidence of LBW children is urgently called for.

A stripe review of the recommendations of these international conferences reveals that, apart from political, social and gender rights, the goal of poverty eradication should receive the highest priority from both national governments and bilateral and international organizations. Poverty is the root cause of hunger, lack of shelter and access to clean drinking water, illiteracy, ill health and other forms of human deprivation. The pathway to meeting the basic needs of every human being is poverty eradication.

Science, technology and economic and social inequity

The contributions of India, China and Greece to scientific discovery and knowledge since prehistoric times are now widely acknowledged. In contrast, modern science in the European tradition is only about 500 years old, dating from the time of Copernicus. Maddox (1998) has urged a clear distinction to be drawn between modern science and its precursors. The interplay between observation and explanation was formerly less important than it is now. A theory qualifies as an explanation only if it can be and has been tested by experiment or observation, employing when necessary measurements more sensitive than the human senses can yield. Similarly, a distinction should be drawn between science and technology. Science helps to advance the frontiers of knowledge, whereas science-based technologies help to advance the frontiers of economic wealth. Maddox (1998) has also emphasized that, while we are right to marvel at what has been accomplished in the past 100 years, we should not forget that there would have been the same sense of achievement at the end of each of the preceding centuries. Thus, we should celebrate many different visions and technologies, both historical and contemporary.

Virginia Postrel (1998), in her book *The Future and its Enemies*, points out that knowledge, like experience, is in many ways cumulative. Dynamism and innovation are about creating the future. However, we should not ignore the past from which the future evolves. It is this concept which led Professor Federico Mayor of UNESCO and the late Commandant Jacques Cousteau to propose the concept of ecotechnology. Ecotechnology is a blend of the ecological prudence of the past and modern science. It involves an interdisciplinary approach and a proactive and continuous interaction among social scientists and technologists working in frontier areas like space and information technologies, biotechnology, nuclear science and renewable energy technologies (see von Weiszäcker *et al.*, 1983, for approaches to technology blending). Ecotechnologies are more knowledge- than capital-intensive and provide opportunities for decentralized production supported by a few key centralized services.

Postrel (1998) points out that 'loss of rural employment and migration from the countryside to the cities causes a fundamental and irreversible shift. It has contributed throughout the world to the destabilization of rural society and to the growth of vast urban concentrations. In the urban slums congregate uprooted individuals whose families have been splintered and whose cultural traditions have been extinguished'. The proliferation of urban slums as a result of the loss of rural livelihoods presents a grave threat to achieving the goal of ensuring every human being access to basic human needs like safe water, sanitation, balanced diets, health care and education.

To develop an effective strategy for poverty eradication, it is important to understand how poverty first arose and why it is affecting developing countries more. Jared Diamond (1997) points out that until the end of the last Ice Age, around 11 000 BC, all peoples on all continents were hunter-gatherers. Different rates of development of different continents occurred between 11 000 BC and AD 1500. While aboriginal Australians and many native Americans remained hunter-gatherers, most of Eurasia and much of the Americas and sub-Saharan Africa gradually developed agriculture, herding, metallurgy and complex political organization.

One of the interesting questions in comparative economic history is the gap in levels of real income between developed and developing countries. David Landes (1969) pointed out that 'Western Europe was already rich before the industrial revolution because of substantial technological progress, not only in the production of material goods, but in the organization and financing of their exchange and distribution. The appropriation of extra-European resources and labour further increased the wealth of Western Europe'. Angus Maddison (1983) generally supports this view. The Industrial Revolution in Europe led to a widening of the prosperity gap between industrialized and developing nations. The transition to the technological and industrialized age also marked the transition to a world with increasing economic inequity.

Roger Farmer (1998) has stressed that, although differences in rates of growth in standard of living seem like small numbers, they can have a very big impact on real standard of living because of the increase each year getting compounded. Today, developing countries face additional handicaps including severe debt and debt-servicing burdens, an unfair trade regime where trade is becoming free but not fair and an expansion in social exclusion through patents and other forms of intellectual property rights.

Fortunately, there are no human differences in intelligence that parallel human differences in technology. Hence, it should be possible to embark upon a dynamic programme for the technological empowerment of the poor. Diamond (1997) points out that people who until recently were technologically primitive – such as aboriginal Australians – speedily master industrial technologies when given opportunities to do so. We have seen in India, especially in the Punjab and Haryana, barely literate farmers acquiring sophisticated electrical and mechanical engineering skills. Therefore, UNESCO, UNDP, the World Trade Organization (WTO), ICSU and other interested multilateral and bilateral donors should develop a plan of action for mobilizing technology, training, techno-infrastructure and trade for poverty eradication. Trade policies should be formulated in such a manner that they will strengthen and not erode the livelihood security of the women and men living in poverty. Developing countries should ensure that their import and export policies are based on a livelihood impact analysis.

The pervasive poverty we witness today is the most serious indictment of contemporary developmental pathways. The poor are poor because they have no productive assets – no land, no education and no technical skill. They earn their livelihood largely through unskilled work. They have been bypassed by modern technological advances. They suffer from a sense of exclusion from the exciting scientific adventures we are witnessing today. Their sense of frustration is enhanced when they see on television the benefits of technological progress enjoyed by a section of humankind. Reaching the unreached and including the excluded have to be important components of the science and technology policy and strategy for the new century, if the huge stock of scientific and technological knowledge and innovations with which we will be entering the next century is to become a blessing for humankind as a whole. A priority task for the Inter-Academy Center proposed by Professor Bruce Alberts, President of the US National Academy of Sciences, should be the closing of the vast knowledge and skill gap prevailing between rich and poor nations on the one hand and between the rich and the poor within all nations. New information technologies provide a unique opportunity for the knowledge and skill empowerment of the poor. The women and men now living in poverty can be helped to experience a better quality of life only by increasing the economic value of their time and labour. A transition from unskilled to skilled work resulting in value addition to labour and time will be needed for enabling the poor to experience a productive and healthy life. Opportunities exist today for achieving such a transition speedily.

Gender dimensions of poverty: women in S&T and S&T for women

UNDP's *Human Development Report* of 1995 states 'human development, if not engendered, is endangered'. The report further states that the revolution towards gender equality must be propelled by a concrete strategy for accelerating progress. The Beijing Platform for Action adopted by the Fourth World Conference on Women on 15 September 1995, says:

'In the past decade, the number of women living in poverty has increased disproportionately to the number of men, particularly in the developing countries. The feminization of poverty has also recently become a significant problem in the countries with economies in transition as a short-term consequence of the process of political, economic and social transformation. In addition to economic factors, the rigidity of socially ascribed gender roles and women's limited access to power, education, training and productive resources as well as other emerging factors that may lead to insecurity for families are also responsible. The failure to adequately mainstream a gender perspective in all economic analysis and planning and to address the structural causes of poverty is also a contributing factor.

'Science curricula in particular are biased. Science textbooks do not relate to women's and girls' daily experience and fail to give recognition to women scientists. Girls are often deprived of basic education in mathematics and science and technical training, which provide knowledge they could apply to improve their daily lives and enhance their employment opportunities. Advanced study in science and technology prepares women to take an active role in the technological and industrial development of their countries, thus necessitating a diverse approach to vocational and technical training. Technology is rapidly changing the world and has also affected the developing countries. It is essential that women not only benefit from technology, but also participate in the process from the design to the application, monitoring and evaluation stages.'

The Beijing Conference recommendations concerning the technological empowerment of women were considered at a meeting of women scientists and technologists in Asia and the Pacific region at the M.S. Swaminathan Research Foundation, Chennai, in December 1996 under the auspices of UNDP and the United Nations Development Fund for Women (UNIFEM). The meeting recommended several institutional and policy devices to enlarge the role of women in science and technology development and dissemination. Recommendations were also made to mainstream gender considerations in ongoing science and technology programmes. A major requirement for women entrepreneurs is flexi-time and flexi-duration of work. Also, women engaged in micro-enterprises supported by micro-credit will need institutional structures which will provide them with the power of scale, particularly in marketing.

An example of the kind of support needed is provided by the Biotechnology Park for Women coming up near Chennai in India. This park will provide centralized services like information, training and electronic marketing facilities for many women entrepreneurs seeking to find avenues for remunerative self-employment. There is need for a global movement for the knowledge, skill and technological empowerment of women living in poverty. Because of the multiple burden on their time, they are overworked and underpaid. Hence, the aim of scientific research designed for helping resource-poor women should be to add economic value to each hour of work and reduce the total number of hours of work. The Biovillage programme of MSSRF aims to achieve these twin goals.

Successful examples of women's technological empowerment need to be replicated worldwide. Opportunities for assured and remunerative marketing will determine the success of the micro-credit supported micro-enterprises now being advocated to end the feminization of poverty. It would be useful if UNIFEM, the International Labour Organisation (ILO), Women's World Banking and WTO undertook a careful study of the public policy support needed at the national and global levels to make women's enterprises supported by micro-credit economically viable.

Science and food and water security

The 20th century began with the rediscovery of Mendel's laws of inheritance. It ended with moving specific genes across sexual barriers with the help of molecular mapping and recombinant DNA technology. The impact of science and technology in every field of crop and animal husbandry, inland and marine fisheries and forestry has been profound. Let me illustrate this, taking the improvement of wheat production in India as an example.

Emerging farming technologies will be based on precision farming methods leading to plant-scale rather than field-scale husbandry. Farming will be knowledge intensive, using information from remote sensing, Geographical Information Systems (GIS), Global Positioning Systems (GPS), and information and computer technologies. Farmers in industrialized countries are already using satellite imagery and GPS for early detection of diseases and pests, and to target the application of pesticides, fertilizer and water to those parts of their fields that need them urgently. Among other recent tools, the GIS methodology is an effective one for solving complex planning, management and priority-setting problems. Similarly, remote-sensing technology can be mobilized in programmes designed to ensure drinking water security.

Let me cite two examples of their value from our recent work.

First, GIS was applied for determining priorities in a programme designed to launch a total attack on hunger in the Dharmapuri district in Tamil Nadu, India. Socio-economic data like the percentage of poor population, percentage of unemployment, literacy rate, and infant and maternal mortality rates were mapped in GIS. The layers were prepared for each factor and registered together. Different levels were given to classify each factor. They were overlaid to get a profile map showing the poorest villages which need to be accorded priority in the hunger-free area programme.

Second, GIS proved to be an invaluable tool in developing strategies for the conservation and sustainable and equitable use of biodiversity. The Gulf of Mannar region in South India is a biological paradise. Unfortunately, anthropogenic pressures and the unsustainable use of coral reefs, sea-grass beds and mangroves are causing serious damage to this priceless heritage. With financial support from the Global Environment Facility (GEF), a Gulf of Mannar Biosphere Reserve Trust is being created by the Government of Tamil Nadu. The aim is to make all stakeholders regard themselves as trustees of this area. This evolution of the Gulf of Mannar Biosphere Reserve into a Biosphere Trust held in trust for posterity is an example of UNESCO's vision of Biosphere Reserves for the 21st century articulated at Seville becoming a reality:

> 'Rather than forming islands in a world increasingly affected by severe human impacts, biosphere reserves can become theatres for reconciling people and nature. They can bring the knowledge of the past to the needs of the future.'

Under a programme of the Government of India designed to provide drinking water to all, groundwater surveys through satellite remote-sensing data were used for hydrogeomorphological mapping. Based on statistics of over 170 000 bore wells dug with these maps, it was found that the success rate of finding water was as high as 92%. Without such data becoming available, it would have been impossible to cover 445 districts of India, totalling over 300 million hectares with diverse terrain, diverse climate and diverse cultural conditions within a few years.

Biotechnology will play an increasingly important role in strengthening food, water and health security systems. Recent widespread public concern relating to genetically modified (GM) food stresses the need for more effective and transparent mechanisms for assessing the benefits and risks associated with transgenic plants and animals. An internationally agreed Biosafety Protocol on the lines recommended in Article 19 of the Convention on Biological Diversity (CBD) is an urgent necessity. Biotechnology companies should agree to the labelling of GM foods in the market. All food safety and environmental concerns should be addressed with the seriousness they deserve. Broad-based national commissions on genetic modification for sustainable food and health security should be set up, consisting of independent professionals, environmentalists, representatives of civil society, farmers' and women's organizations, mass media and the concerned government regulatory authorities. This will help to assure both farmers and consumers that the precautionary principle has been applied, while approving the release of GM crops.

Article 27(b) of the TRIPS component (trade-related intellectual property rights) of the World Trade Agreement will come up for review later in 1999. All nations should agree to incorporate in this clause the ethics and equity principles enshrined in articles 8(j) and 15 of CBD. The World Intellectual Property Organization (WIPO), which has launched a study of the need to recognize the intellectual property rights of the holders of traditional knowledge, should complete this study soon and help to make the principles of ethics and equity the foundation of intellectual property rights.

UNESCO, FAO and WHO should formulate a Universal Declaration on the Plant Genome and Farmers' Rights along lines similar to the *Declaration on the Human Genome and Human Rights*. If such steps are taken, biopiracy will give way to symbiotic biopartnerships. Conservation and commercialization will then become mutually reinforcing. Such a step will not only help to strengthen biodiversity conservation but will make an important contribution to poverty alleviation. The life sciences industry based on the modification of living organisms to create new products and services will then have a sustainable future.

The biotechnology industry should lose no further time in giving a helping hand to evolve internationally agreed protocols for biosafety, bioethics and biosurveillance. If this is not done, biotechnology and other life science industries, which can be invaluable allies in a global 'science and technology for basic human needs movement', will remain clouded in controversies, suspicion and rich-poor conflicts.

Emerging scientific revolutions and an ecology of hope

Fortunately, as we approach the new century we are experiencing three major revolutions in science and technology, which will influence agriculture and industry in a fundamental manner. It will therefore be appropriate to make a brief reference to them:

- the gene revolution – which provides a molecular understanding of the genetic basis of living organisms, as well as the ability to use this understanding to develop new processes and products for agriculture, industry, the environment, and for human and animal health;
- the ecotechnology revolution – which promotes the blending of the best in traditional knowledge and technology with frontier technologies such as biotechnology, space and information technologies, renewable energy and new materials;
- the information and communication revolution – which allows a very rapid growth in the systematic assimilation and dissemination of relevant and timely information, as well as a dramatically improved ability to access the universe of knowledge and communicate through low-cost electronic networks.

In principle, these three types of advance – when coupled with improvements in management and governance – greatly increase the power of a scientific approach to genetic improvement, the integrated management of natural resources and ecosystems, and the management of local and regional development strategies. Ecotechnologies enable the adoption of ISO 9000 and ISO 14000 standards of environmental management. These scientific revolutions seem to be proceeding at an ever-increasing pace, with most of the action occurring in industrialized nations. Also, new discoveries of great relevance to sustainable food and health security are coming under the purview of proprietary science, since they are covered by intellectual property rights. How then can we mobilize recent advances in science and technology for meeting the basic needs of the economically and socially underprivileged sections of the human family?

The gene revolution

The past 10 years have seen dramatic advances in our understanding of how biological organisms function at the molecular level, as well as in our ability to analyse, understand and manipulate DNA molecules, the biological material from which the genes in all organisms are made. The entire process has been accelerated by the Human Genome Project, which has poured substantial resources into the development of new technologies for working with human genes. The same technologies are directly applicable to all other organisms, including plants. Thus, a new scientific discipline of genomics has arisen. This discipline has contributed to powerful new approaches in agriculture and medicine and has helped to promote the biotechnology industry.

Several large corporations in Europe and the USA have made major investments in adapting these technologies to produce new plant varieties of agricultural importance for large-scale commercial agriculture. The same technologies have equally important potential applications for addressing food security in the developing world.

The key technological developments in this area are:

- genomics: the molecular characterization of species;
- bioinformatics: data banks and data processing for genomic analysis;
- transformation: introduction of individual genes conferring potentially useful traits into plants, trees, livestock and fish species;
- molecular breeding: identification and evaluation of useful traits by use of marker-assisted selection, which greatly speeds up traditional breeding processes;

- diagnostics: identification of pathogens by molecular characterization;
- vaccine technology: use of modern immunology to develop recombinant DNA vaccines for improved control against lethal diseases of animals and fish.

Let me cite one example from the work of MSSRF scientists to illustrate the value of the new tools. As a part of the anticipatory research programme to meet the consequences of sea-level rise arising from global climate change, genes responsible for conferring the ability to withstand sea-water intrusion were identified in a few mangrove species through molecular mapping. They have been transferred to annual economic plants through recombinant DNA technology.

The sequencing of the genome of rice (*Oryza sativa* L.cv.Nipponbare) by an international consortium supported by the Rockefeller Foundation and the International Rice Research Institute will permit allele mining for all genes of rice and possibly for other cereals. Thus, altogether unforeseen opportunities for creating novel genetic combinations have been opened up.

The ecotechnology revolution

Knowledge is a continuum. There is much to learn from the past in terms of the ecological and social sustainability of technologies. At the same time, new developments have opened up new opportunities for developing technologies which can lead to higher productivity without adverse impact on the natural resource base. Blending traditional and frontier technologies leads to the birth of ecotechnologies with combined strengths in the following areas:

- economics;
- ecology;
- equity;
- employment;
- energy.

The information technology revolution

New communication and computing technologies are already influencing life on our planet in a profound manner.

- Access to the Internet will soon be universal and it can provide unrestricted low-cost access to information, as well as highly interactive distance learning. The Internet will not only facilitate interactions among researchers, but also greatly improve their ability to communicate effectively with the potential users of their research knowledge.
- Computing makes it possible to process large-capacity databases (libraries, remote-sensing and GIS data, gene banks) and to construct simulation models with possible applications in ecosystem modelling, preparation of contingency plans to suit different weather probabilities and market variables.
- The software industry is continuously providing new tools that increase research productivity and create new opportunities for understanding complex agroeco systems.
- Remote-sensing and other space satellite outputs are providing detailed geographic information useful for land and natural resources management.

The promotion of ecotechnology development and dissemination, the effective adoption of integrated systems of gene and natural resource management and the effective harnessing of information technologies should become essential elements of the ‘science and technology for basic human needs’ movement.

Harnessing resources for a ‘science for basic human needs’ movement

Since the onset of the Industrial Revolution in Europe, technology has been a major source of economic inequity among nations and among communities within nations. If technology has been a cause of economic and social inequity in the past, today we have an opportunity for making technology an ally in the movement for social, gender and economic equity. Modern information technology provides this opportunity. Knowledge and skill empowerment can now be achieved at a fast pace. However, the technological and skill empowerment of the poor cannot be achieved through programmes designed on the basis of a patronizing and a top-down approach. The information provided should be demand- and need-driven and the knowledge centres should preferably be managed by women belonging to the socially and economically underprivileged sections of the society. Our aim in the early part of the coming century should be the initiation and spread of a Knowledge Revolution for ending economic and gender inequity.

The accomplishment of the tasks I have outlined so far requires considerable technical, managerial and financial resources. Scientists of the International Peace Research Institute, Oslo, have studied the causes of armed conflicts during the last 10 years. They found that violent conflicts in most cases could be traced to economic rather than ideological differences (de Soysa and Gleditsch, 1999). They have hence suggested that investing in agriculture which helps to promote food and livelihood security in many nations is an effective strategy for preventing future wars, eradicating poverty, preventing environmental destruction and reducing violence. Unfortunately, even now, far too high a proportion of national gross domestic product (GDP) is being spent on arms and military equipment as compared to programmes designed for poverty eradication and meeting the basic needs of the underprivileged sections of humankind. The so called 'peace dividend' still remains only in the realm of possibility (Swaminathan, 1994).

The year 2000 has been appropriately designated the International Year for the Culture of Peace. Without peace and human security, it will not be possible to ensure the basic human needs of every child, woman and man. It will be appropriate to recall on this occasion what Dwight D. Eisenhower, a great war leader who subsequently became President of the USA, stated on 16 August 1953:

'Every gun that is made, every warship launched, every rocket signifies in the final sense a theft from those who are hungry and are not fed, from those who are cold and are not clothed. This world in arms is not spending money alone. It is spending the sweat of its laborers, the genius of its scientists, the hopes of its children.'

Harnessing science and technology for fulfilling the basic minimum needs of every child, woman and man living on our planet will be possible only if this message becomes central to the ethos of human culture.

Conclusion

To sum up, we are ending the 20th century with a huge stockpile of scientific discoveries and technological innovations. This stockpile is more than adequate to help all nations to provide every adult human being with an opportunity for a healthy and productive life and every newborn child a happy future. It is therefore a sad commentary on our political, social and spiritual value systems that the number of children, women and men living in poverty today exceeds the entire human population of our planet at the beginning of the century. Unsustainable lifestyles and degrading poverty co-exist everywhere. This is the greatest failure of the developmental pathways and strategies adopted during the century. Can we lay the foundation at this Conference for the emergence of a new political, social and scientific commitment to end the irony of widespread human misery and deprivation prevailing in the midst of uncommon opportunities for a better common present and future for all? In my view we can, provided every one of the nearly 2 billion persons who are enjoying a healthy and productive life today will keep the following the advice of Mahatma Gandhi as the guiding principle in his/her day-to-day life and work:

'Recall the face of the poorest and the weakest man whom you have seen and ask yourself if the steps you contemplate are going to be of any use to him. Will he gain anything by it? Will it restore to him control over his own life and destiny?'

In other words, the formidable power of science and technology can benefit mankind only if we know how to temper it with humanism. Let us hope the new millennium will throw up a new crop of leaders of science who will be able to usher in an era of humanistic science. It is the duty of scientific establishments and science academies to nurture and foster the growth of young men and women research leaders capable of initiating and managing change in goals and strategies in the coming century.

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KEYNOTE SPEECH

The scientist as global citizen

Neal Lane
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(Delivered by **Bruce Alberts***, President, National Academy of Sciences, Washington, DC, USA)*

Neal Lane wanted me to say at the start that it was a great honour for him to be one of the opening speakers at this Conference. By bringing together thousands of scientists and policy-makers, this meeting provides a compelling demonstration of both the scope and the importance of scientific knowledge. We are all privileged to be at the centre of an activity that will have such a profound influence on humanity's future. And we are fortunate to be working in science and technology during this exciting time of ferment, progress and change.

Looking to the future, we see that we have a busy agenda ahead of us. We must coordinate research projects that are global in scale. We must choose, from an ever-widening array of possible projects, those that have the greatest potential scientific returns. We must ensure that scientists everywhere on the planet are able to contribute effectively to problems that will require all of the effort we can muster.

The growth of scientific knowledge is certain to be the single most influential force of the next 100 years, as it has been for the past 100 years.

We cannot predict how science will continue to change the world, but it will change it profoundly. We can only lament, as did the American Benjamin Franklin 200 years ago, that we will not be here a century from today to see the wonders that science has wrought.

The implications of science for society go well beyond the results of research. We can learn much about 21st century society by examining the nature of science. We can also predict that the links between science and society will become tighter and more numerous.

One critical aspect of this close relationship between science and society is the increasing role for what Neal Lane has termed 'global citizen-scientists'. Our social institutions have an increasing need for individuals who can stand at the interface between new knowledge on the one hand and major national and international societal needs on the other hand, and act as a channel to pass information in both directions between them. These individuals have responsibilities that extend both internally to the scientific community and externally to the broader society.

There are two social trends that are generating the need for global citizen-scientists. The first trend is the advent of a global, information-based economy and the second is the growing internationalization of science itself.

During the second half of the 20th century, the industrialized societies were undergoing a transformation so profound that some have labelled it the third major revolution in human history: after the development of agriculture and then the Industrial Revolution. This transformation has many aspects, some of which are scientific, some technological and some purely cultural. But the driving force behind many of these changes is the transition from societies based on tangible resources to societies based on knowledge.

For the past several centuries, the modern world has been organized around resources, such as land, fossil fuels, heavy industry or armaments. These resources will remain important in the 21st century, just as the Industrial Revolution did not diminish the importance of agriculture. But the most valuable resource of the 21st century will not be a tangible object. It will be knowledge – along with the educated and well-trained people who can take advantage of that knowledge – in short, people who can think!

Knowledge differs in a fundamental way from conventional resources. Physical resources are inherently limited. And their distribution is a limited-sum game. In contrast, the distribution of knowledge is an unlimited-sum game. Knowledge can be reproduced at virtually no cost. The pursuit of knowledge is self-catalytic: knowledge generates more knowledge in an exponentially increasing, feedback spiral.

The shift towards a knowledge-based economy has revolutionary implications for national governments. Consider foreign policy. Diplomacy changes in fundamental ways when information from CNN television reaches policy-makers and the public in real time, or when industrial competition rivals military competition as a determinant of national power. The foreign affairs agencies and ministries of countries around the world now face the formidable task of reinventing themselves for the information age.

The ground rules for governments as a whole have changed. Non-governmental organizations now have budgets in the billions of dollars and deliver more official developmental assistance than does the United Nations. They are active partners in international negotiations over such crucial issues as the global environment, the delivery of health care and debt restructuring.

The fundamental relations among governments are themselves being transformed by the advent of the information age. North-South relations typically have been dominated by considerations of natural resources. In the 21st century, issues affecting the flow of knowledge among industrialized and developing nations will take centre stage.

Science has in many ways been the instigator of these changes, yet it, too, is being substantially altered by the growing role of information in modern society. These trends call for an increased involvement by global citizen-scientists.

In recent years, Neal Lane has become famous among US scientists and engineers for his focus on the need for scientists to use their technical knowledge to help address societal objectives. In their new capacity of ‘civic scientists’, scientists and engineers must step outside their campuses, laboratories and institutes to engage in active dialogue with their fellow citizens. They must learn about the many ways in which technical knowledge is used in the broader society and discuss with their fellow citizens the issues that are critical to the future.

Of course, this does not mean that researchers should reduce their efforts to identify and probe the seminal scientific and technical questions, wherever they may lead. The history of science demonstrates the enormous benefits that scientific knowledge can deliver to society, very often in completely unanticipated ways. As a global scientific community, we must maintain a strong and balanced research effort to push forward the frontiers of fundamental knowledge wherever we can. Only in that way will we make the great discoveries and advances that enrich our culture and that will ultimately lead to a healthier and more prosperous life for all inhabitants of our planet.

But science has become so integrated into the rest of society that scientists must also look beyond the intriguing research questions into questions that examine the ways in which new scientific knowledge may be most effectively used in society.

Engaging in a dialogue with the public involves listening as well as speaking. There is a great need for the public to have a better understanding of science. But there is an equally great need for scientists to have a better understanding of the public.

It is particularly important that this dialogue with scientists extend to policy-makers. Scientists traditionally have served as advisers to policy-makers, providing input as needed to policy decisions. Now the flow of information in the opposite direction must intensify. Scientists must listen carefully to the needs expressed by policy-makers and work creatively and energetically to meet those needs.

When Neal Lane makes this argument to US audiences, the implied context is typically local, regional and national. He urges scientists and engineers to get involved in societal issues in their communities, in their states, or at the national level.

But the case for the civic scientist applies just as forcefully at the international level. Of course, science has always been among the most international of human activities. The Russian writer and physician Anton Chekhov made this point when he observed: ‘There is no national science just as there is no national multiplication table’. Similarly, the statutes of the International Council for Science (ICSU) call upon the organization to ‘observe and actively uphold the principle of the universality of science’.

In recent decades, this international character of science has become institutionalized in common practice. The percentage of papers with authors from more than one country has steadily grown. Scientific meetings draw attendees from around the world. The growing sophistication of the scientific communities in many countries has diversified and strengthened our mutual pursuits. This will only continue.

Modern communications have been both a tool and a catalyst in this internationalization of science. The Internet now makes it as easy to communicate with someone on the other side of the world as with someone across the hall. The international scientific community has become what Marshall McLuhan termed a global village. The consequences of this rapid communication and sharing of ideas are not only scientific; they are social and cultural as well.

A second factor contributing to the internationalization of science is the increasing number of fundamental scientific challenges that are either too complex or too resource intensive for any one nation – or those that are intrinsically global in scope and importance.

There are many such areas of investigation, from the Human Genome Project to global change research to elementary particle physics. Neal Lane wanted to mention one with which he has had some recent experience. Since 1995, UNESCO has provided critical financial support for the formation and conceptual design of the Pierre Auger project, which consists of a pair of observatories dedicated to determining the origins of the highest-energy cosmic rays that strike the Earth.

These cosmic rays are among the most mysterious phenomena in nature. An observatory now under construction in Argentina, which is arranged in a grid 10 times the size of Paris, will record the so-called air 'showers' caused by the entry of these high-energy particles into the atmosphere. A second observatory, to be built at a location yet to be determined, will allow studies of cosmic rays that strike the Northern Hemisphere. To date, this project has involved more than 250 scientists from almost 20 countries. It is an excellent example of the kinds of collaborative efforts that organizations like UNESCO and ICSU can generate.

A third factor behind the internationalization of science is the emergence of issues with dire societal consequences that transcend national boundaries. These include climatic disruption, loss of biodiversity, the degradation of marine environments, the emergence of new infectious diseases, the proliferation of nuclear materials and international trafficking in narcotics.

Several remarkable statistics help to convey the magnitude of these problems. Between one-third and one-half of the land surface of the Earth has been transformed by human action. More than half of all the accessible fresh water on the planet is now put to use by humans. Two-thirds of our major marine fisheries are fully exploited, overexploited or depleted.

The practical importance of these problems does not make the science involved in addressing them less challenging or less intellectually stimulating. On the contrary, these problems with profound societal relevance have become the focal points around which much of today's most exciting research is arrayed – issues such as global climate change, industrial ecology and the properties of complex computer networks.

We need also to emphasize what I believe is the greatest problem we face – the remaining and, in many cases, the growing inequities within and among nations. This is the point made so well today by both Dr Vargas and Dr Swaminathan. Pervasive poverty degrades the dignity of all of us, no matter where it occurs – North, South, East or West. There is a global imperative to close the widening gap between the haves and have-nots in the world – not through hand-outs, but through building knowledge and very importantly the capacity to use it.

The two trends that I have described – the advent of an information-based economy and the growing internationalization of science – reflect and reinforce each other. In turn, these two trends have created new roles and responsibilities for scientists and engineers.

These responsibilities are of two types, which I characterized earlier as looking inward towards the rest of the scientific community and looking outward towards the broader society. With regard to the first – those directed towards the scientific community – scientists have long appreciated the importance of maintaining strong domestic science and technology bases. Furthermore, they recognize that advances by one research group or in one discipline contribute to the progress of other groups or disciplines, so that strengths in any strengthen the whole enterprise.

With the rapid internationalization of science, the same arguments apply just as forcefully on a global scale. By helping science anywhere, scientists strengthen science everywhere. This win-win characteristic of modern science is a consequence of the cumulative nature of scientific knowledge. Science has undergone incredible growth over the past half-century. More than 80% of all the scientists who have ever lived are alive at this moment. Of all the science ever performed in human history, most has been done by people who are alive right now.

This growth of the scientific community has produced a tremendous quickening of scientific thought. Advances anywhere in the world race along formal and informal lines of communication, speeding the generation of more knowledge. Strengthening the worldwide scientific community is therefore to the advantage of all scientists.

There are many possible ways for scientists to strengthen the international scientific community. For example, the US Government manages approximately 33 bilateral science and technology 'umbrella agreements' with other nations. Under these umbrella agreements are hundreds of implementing agreements between US technical agencies and their counterparts in those countries. By engaging in collaborative efforts under these agreements, scientists advance their own research programmes, while also contributing to the infrastructure of international cooperation.

These international collaborations have many other benefits. For example, they have proved to be an extremely valuable tool for engaging with former Warsaw Pact countries at the end of the Cold War. Based on the success of those agreements, the USA is pursuing similar cooperative efforts with other countries in transition, including Russia and South Africa.

The internal responsibilities towards the scientific community that I have been discussing are important, but the responsibilities of scientists do not stop there.

The major problems facing our global society – such as poverty, environmental degradation, disease and unsustainable energy production – are complex human problems. None of these problems will be solved solely with science and engineering. But none will be solved without science and engineering.

There are many examples of the ways in which scientists and engineers have stepped up and begun to grapple with these questions, and I'll cite just a few. For example, President Clinton's Committee of Advisors on Science and Technology – called by its initials, PCAST – has taken on a number of crucial international issues. In one such recent effort, they looked at energy research and development with particularly high pay-offs to future society. As the world moves towards competitive energy markets, it is important for governments to build mechanisms into these markets that can advance public benefits. For example, the PCAST report encouraged increased collaboration with developing countries on technology and environment issues, international demonstration and commercialization activities, and support for equitable access to energy resources.

Neal Lane also wanted to emphasize the good example set by the scientists, engineers and policy-makers who are attending this meeting. We are here to strengthen existing mechanisms of cooperation in science, as well as between scientists and policy-makers, and to create new mechanisms that will address both national and international needs. There are few more important tasks in our interconnected world.

The years ahead will see many new and exciting ways in which scientists can contribute to this task. For one, scientists have an opportunity and a responsibility to become much more engaged in foreign affairs. As I mentioned earlier, traditional diplomacy faces great challenges in adapting to a networked world. By working with or within foreign service agencies, scientists can help them make the transitions needed to deal with our new knowledge-based global system.

Finally, scientists have many new roles to play in education. Fostering a continued, lifelong engagement in science and technology among citizens of all ages is a challenge that both Neal Lane and I are addressing in the USA. But all countries need to build a cadre of well-trained scientists and engineers who can work at the frontiers of science and its applications. And all countries need to foster public understanding of science and technology so that people support and can take advantage of the products of new knowledge. As with science itself, excellence in science education should know no national boundaries. There is much here also that we all need to begin to share.

Let me end by admitting that the world today faces great challenges – as severe as any that human beings have ever faced. We scientists could declare the task of solving these problems too great, too complex, and thus impossible. We could then go back to focusing exclusively on our narrow scientific concerns. But I would draw a parallel with the founding of the United Nations. There were some who said it could not be done and should therefore not be attempted. But there were many more who said: 'This will not be easy, but we cannot risk not trying'.

It is certain that our responsibilities extend beyond the world of science. We are the ones who will help determine the ways in which new knowledge intersects with societal goals and values. We are the ones who can stand at the crossroads of human knowledge and human needs, and help our world chart the course ahead. This is a challenging task, but also a necessary and an important one. Science has been a great source of good in our world. It had an important role in my country's own revolution, through which we won our independence. One of the architects of the US government, and our third President, was Thomas Jefferson, who – as many of you know – was a practising scientist.

I believe that people all over the world – not just Americans – can look up to Jefferson as a model of the civic scientist. Jefferson loved scientific inquiry and he made it a practice to carry in his pockets some of the scientific tools of his day – thermometer, surveying compass, magnifying glass, even a small globe. But he coupled his love of science with a passion for freedom and human rights and it is for these activities that he is famous today. In fact, Jefferson saw a link – not a contradiction – between the two main pursuits of his life. He wrote, 'The main object of all science is the freedom and happiness of man.' It is our responsibility to continue to strive for Jefferson's noble goal.

Thank you for the privilege of being able to address this great Conference.

KEYNOTE SPEECH

Science and human values

Joseph Rotblat
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Should scientists be concerned with the ethical issues and the social impact of their work? Should they accept responsibility for the human and environmental consequences of scientific research? Those questions did not arise in the distant past, because there hardly were such consequences. In those days science had no role in the day-to-day life of people or – with a few exceptions, such as Archimedes and Leonardo da Vinci – in the security of states. Science was largely the pursuit of gentlemen of leisure. They would collect plants or fossils; they would gaze at the sky and note unusual events. There was no Internet then, so they communicated their observations to other gentlemen with similar hobbies at gatherings of a social character, a sort of salon entertainment. The impulse for those pursuits was sheer curiosity – the same that drives scientists today – with no proclaimed practical aims.

In the course of time, science began to be taken up as a full-time profession; learned societies and academies of science were established, with highly exclusive memberships, and this widened even further the detachment of scientists from society. When the Royal Society – which is now the national academy of sciences in the UK – was formed 340 years ago, one of its founders, the famous physicist Robert Hooke, stipulated that the Society 'should not meddle in Divinity, Metaphysicks, Moralls, Politicks, Grammar, Rethorick or Logick'. This rather odd assortment of banned topics does not figure in the Charter of the Royal Society, but the spirit of exclusivity is still there, in the election to Fellowship. In the list of objectives of the Royal Society, the first item is 'To recognise excellence in science and its application, through election to the Fellowship...'. The procedure for election of members is still one of the main preoccupations of academies.

The detachment of scientists from general human affairs led them to build an ivory tower in which they sheltered, pretending that their work had nothing to do with human welfare. The aim of scientific research – they asserted – was to understand the laws of nature; since these are immutable and unaffected by human reactions and emotions, these reactions and emotions had no place in the study of nature.

Arising from this exclusivity, scientists evolved certain precepts about science to justify the separation from reality. These precepts included: 'science for its own sake'; 'scientific inquiry can know no limits'; 'science is rational and objective'; 'science is neutral'; 'science has nothing to do with politics'; 'scientists are just technical workers'; 'science cannot be blamed for its misapplication'. John Ziman, in a paper on the basic principles of the social responsibility of scientists (in a joint Pugwash-UNESCO project in 1982) analysed each of these postulates and found them all wanting in the current context.

The 'ivory tower' mentality was perhaps tenable in the past, when a scientific finding and its practical application were well separated in time – the time interval between an academic discovery and its technical application could be of the order of decades – and implemented by different groups of scientists and engineers. Pure research was carried out in academic institutions, mainly in universities, and the scientists employed there usually had tenure; they were not expected to be concerned about making money from their work. Taking out of patents occurred very infrequently and was generally frowned upon. This enabled academic scientists to absolve themselves from responsibility for the effects their findings might have on other groups in society.

On the other hand, the scientists and technicians who worked on the applications of science were mainly employed by industrial companies whose chief interest was financial profit. Ethical questions about the consequences of the applied research were seldom raised by the employers and the employees were discouraged from concerning themselves with these issues. All this has changed. The picture that I have presented is so much different from current practices in science that we may as well speak of being in a different set-up.

The tremendous advances in pure science, particularly in physics during the first part of the 20th century and in biology during the second half, have completely changed the relation between science and society. Science has become a dominant element in our lives. It has brought great improvements in the quality of life, but also grave perils: pollution of the environment, squandering of vital resources, increase in transmittable diseases and, above all, a threat to the very existence of the human species on this planet through the development of weapons of mass destruction.

The hugely increased role of science in the life of the community, brought about by the great discoveries in science, has in turn resulted in an immense increase in the magnitude of the scientific endeavour; a process of positive feedback, in which success breeds further success. Thus, we saw an exponential growth in the number of scientists and technicians; in the number of publications; in the number and size of scientific meetings. In parallel with this there has been a radical change in the methodology of scientific research, its scope, its tools, its very nature. We can truly speak about a scientific revolution.

Not all of the success was propitious. For example, the success of the Manhattan Project during the Second World War brought home to military leaders the great importance of science, particularly physics; they became eager to provide financial support to any project, even if remote from military applications. No peer review of the scientific value of these projects was required, with the result that some bad science was done and much money was wasted. Industry, with its close connections with military establishments, also increasingly promoted research projects.

Governments, always on the lookout for ways to reduce spending, were only too eager to unload on industry the burden of scientific research. Gradually this resulted in a definite shift in the way scientific research was supported. Universities were told that they had to seek financial support from industry, indeed that their research must be such as to be financially self-supporting. In some disciplines, such as molecular biology and genetic engineering, much of the research is being funded by industry, largely the pharmaceutical industry, and the main purpose is to secure patents from the discoveries. Financial profit, rather than intellectual advancement, seems to have become a major motivation for research.

An important outcome of the change of emphasis in scientific research is the narrowing of the gap between pure and applied science. In many areas this distinction has become very difficult to discern. What is pure research today may find an application tomorrow and become incorporated into the daily life of the citizen next week (or even earlier if it has military value). Scientists can no longer claim that their work has nothing to do with the welfare of the individual or with state politics.

Scientists cannot make such claims, but many of them do. Amazingly, many scientists still cling to the ivory tower mentality, they still advocate a laissez-faire policy for science. Their logic rests mainly on the distinction between pure and applied science. It is the application of science that can be harmful, they claim. As far as pure science is concerned, the only obligation on the scientist is to make the results of research known to the public. What the public does with them is their business, not that of the scientist.

As already shown, the distinction between pure and applied science is largely non-existent. And the amoral attitude adopted by those scientists is unacceptable. It is – in my opinion – an immoral attitude, because it eschews personal responsibility for the likely consequences of one’s actions.

We live in a world community with ever-greater interdependence, an interdependence due largely to technical advancement arising from scientific research. An interdependent community offers great benefits to its members, but by the same token it imposes responsibility on them. Every citizen has to be accountable for his/her deeds; we all have a responsibility to society.

This responsibility weighs particularly heavily on scientists for the very reason stated above: the dominant role played by science in modern society. Michael Atiyah, former President of the Royal Society and currently President of Pugwash, further developed the reasons for the special responsibility of scientists. In his 1997 Schrödinger Lecture, he said: ‘Scientists will understand the technical problems better than the average politician or citizen and knowledge brings responsibility’.

Both in that lecture and in a presidential address to the Royal Society, Sir Michael stressed the need for scientists to take responsibility for their work for yet another reason: the consequences for science of having a bad public image. The public does hold scientists responsible for the dangers arising from scientific advance: nuclear weapons are a menace and the public rightly blames the scientists; human cloning is distasteful and viewed by the public as immoral, and science is castigated for the few scientists that want to pursue it. The general public, through elected governments, has the means to control science, either by withholding the purse, or by imposing restrictive regulations harmful to science. Clearly, it is far better that any control should be exercised by the scientists themselves.

It is most important that science improve its public image, that it regain the respect of the community for its integrity and re-establish trust in its pronouncements. Scientists must show by their conduct that it is possible to combine creativeness with compassion: letting the imagination roam with caring for fellow creatures, venturing into the unknown yet being fully accountable for one's doings.

I hope that this World Conference on Science will finally convince the scientific community that modern science must take human values into account. By adopting the *Declaration on Science* and the document *Science Agenda – Framework for Action*, the participants in this Conference commit themselves to taking responsibility for the ethical issues arising from the pursuit of science.

The fulfilment of this commitment calls for certain measures to be taken. I would like to make a few suggestions of concrete measures, but first a recapitulation of the purpose of science. While the main purpose is simply to push forward the frontiers of knowledge, this pursuit should contain an element of utility, namely, benefit to the human community. In this respect I find a statement made nearly 400 years ago by Francis Bacon fully applicable to the present time: 'I would address one general admonition to all: that they consider what are the true ends of knowledge, and that they seek it not either for pleasure of the mind, or for contention… but for the benefit and use of life… that there may spring helps to man, and a line and race of inventions that may in some degree subdue and overcome the necessities and miseries of humanity.' To bring it up-to-date, I would add '…and to avert the dangers to humanity'.

These desiderata should be expressed in an ethical code of conduct for scientists, and formulated in some sort of a Hippocratic Oath. An ethical code of conduct for medical practitioners has been in existence for nearly two and a half millennia. In those days – and still today – the life of a patient was literally in the hands of the doctor and it was essential to ensure that the doctor would wield his power responsibly, with the care of the patient being his foremost duty. Hence the Hippocratic Oath taken by doctors when they qualify.

Nowadays, scientists can be said to have acquired a somewhat similar role in relation to humanity. The time has thus come for some kind of oath, or pledge, to be taken by scientists when receiving a degree in science. At the least, it would have an important symbolic value, but it might also generate awareness and stimulate thinking on the wider issues among young scientists.

Various formulations of oaths, to suit specific conditions, have been suggested and introduced by some professions. A formulation suitable for young scientists, to be taken at graduation, has been adopted by the Student Pugwash Group in the USA. This Pledge, already taken by thousands of young scientists in several countries, reads: 'I promise to work for a better world, where science and technology are used in socially responsible ways. I will not use my education for any purpose intended to harm human beings or the environment. Throughout my career, I will consider the ethical implications of my work before I take action. While the demands placed upon me may be great, I sign this declaration because I recognize that individual responsibility is the first step on the path to peace.'

It should be noted that the Pledge refers to harm to the environment, as well as to human beings, that may result from science and technology. Universities should be asked to adopt the practice of graduates in science taking the Pledge at degree ceremonies. A precondition for this should be the introduction to the university curriculum of a course of lectures on the ethical aspects of science.

While it is very important that new entrants into a scientific career become aware of their social responsibilities, it is also important that senior scientists acknowledge their own awareness of such responsibilities. For this purpose, I suggest that national academies of sciences (or corresponding bodies in countries where there are no academies) should explicitly include ethical issues in their terms of reference. The charters of some academies already contain clauses that allow them to be concerned with the social impact of scientific research. But I would like to see these clauses made mandatory; there should be explicit statements that ethical issues are an integral part of the work of scientists.

As a follow-up to this general commitment, I suggest a specific task for the academies: the setting up of ethical committees – another practice borrowed from medicine. In many countries, a research project that involves patients has to be approved by the ethical committee of the hospital, to ensure that the investigation will not put the patient's health and welfare at significant risk. This practice should be extended to research work in general, but perhaps, in the first instance, to genetic engineering, an area of research which has a direct impact on the health of the population.

I suggest that ethical committees, composed of eminent scientists from different disciplines, should be set up for the task of examining potentially harmful long-term effects of proposed research projects. Such projects have normally to be reviewed for other reasons – for scientific merit, for budget justification, for compatibility with other projects, etc. To these I would add ethical considerations and possible harmful applications. The assessment for this could be carried out in parallel with the other assessments and would not therefore cause a significant delay. The ethical committees should work under the auspices of the national academies of sciences in the country, but it would be essential for the criteria used in the assessment of projects to be agreed internationally so that the same standards are applied everywhere. The International Council for Science (ICSU) seems to be the appropriate organization to coordinate the task. In some countries ethical vetting is already carried out by formal or informal bodies, but there is a need for general acceptance and for an implementation mechanism, and this is where ICSU should come in.

While on the subject of organizations of scientists, I should mention that there is also an important role for fully independent organizations specifically concerned with the ethical issues arising from scientific research and its applications. A large number of such organizations of scientists are in existence. Among those familiar to me I would mention the Federation of American Scientists, the Forum on Physics and Society of the American Physical Society, the Union of Concerned Scientists, Scientists for Global Responsibility, and – above all – the Pugwash Conferences on Science and World Affairs, to which I have already alluded several times. Non-governmental organizations (NGOs) can take on the task which the academies of science might find it inexpedient to be involved with, because of their restrictive terms of reference; in some countries academies are officially or indirectly organs of government establishments.

I have mentioned earlier a negative aspect of the current trend of scientific research, namely, that it is becoming motivated by financial gain. Frequently, this is detrimental to one of the main postulates of scientific research: that results of research are available to everybody. The financial promoters of research projects tend to impede the publication of findings, either prohibiting it altogether or delaying it considerably. The whole practice of patenting scientific findings goes against a basic tenet of science; it also affects the pursuit of science by exacting payment for the use of essential materials, or the technology covered by patent rights. To overcome these inequities, action should be initiated, for example to ban the granting of patents for certain results of scientific research, particularly on basic materials such as genes. A radical solution would be to buy out the patents on findings that directly or indirectly affect human health.

Secrecy in scientific research for the financial profit of a commercial company is only one aspect of a multi-faceted problem. Another is secrecy imposed by scientists themselves, in the pursuit of a Nobel Prize, for example, to safeguard against other scientists stealing their ideas or techniques. This too may cause a delay in the publication of results and thus be an impediment to scientific progress. It is an ethical issue which scientists have to tackle among other undesirable practices, such as announcing results to the media before their presentation for peer review, or publication of fraudulent research.

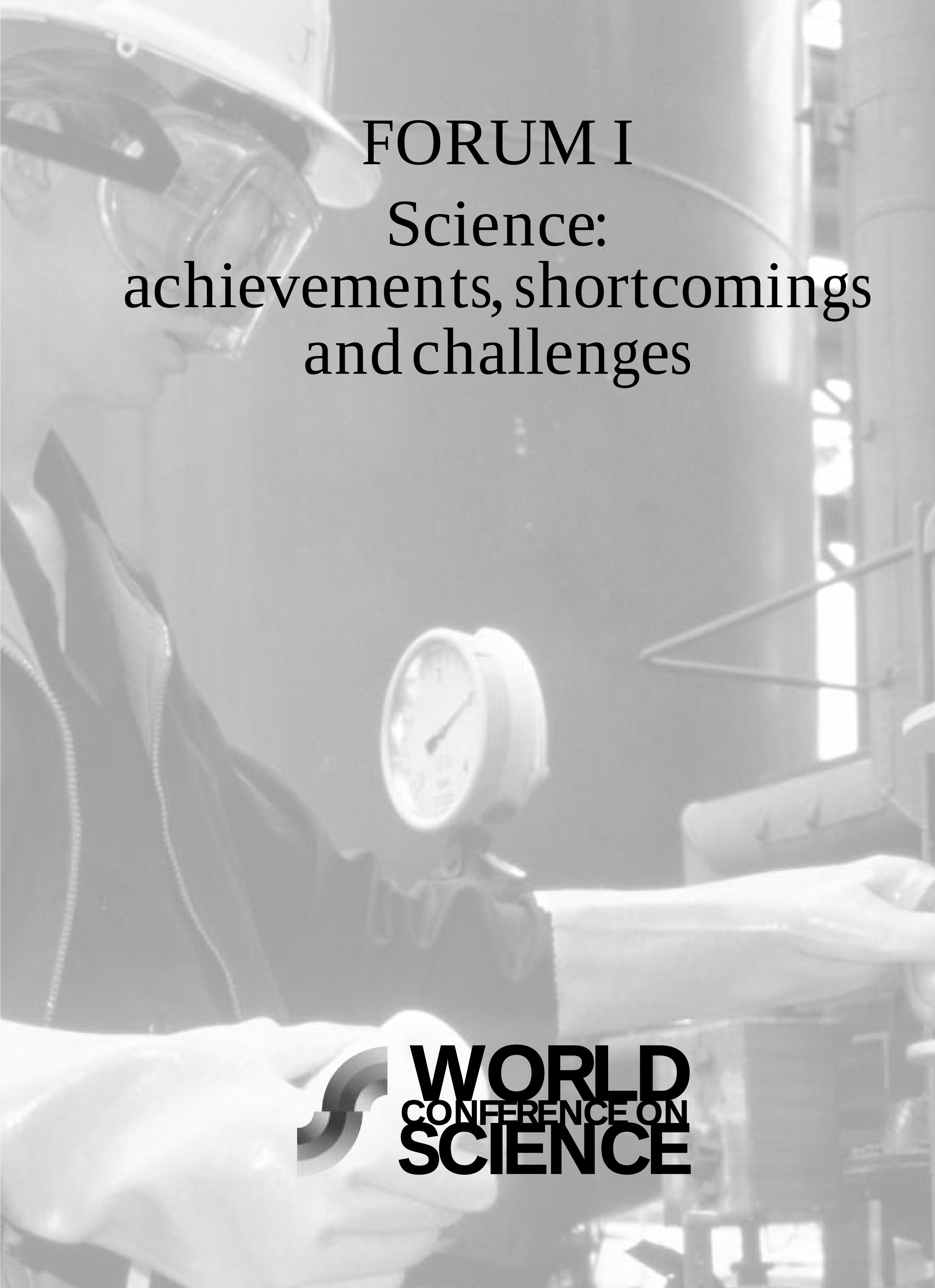
However, the worst aspect of secrecy is that imposed by governments in national research laboratories, such as Los Alamos or Livermore in the USA, the Chelyabinsks or Arzamases in Russia, Aldermaston in the UK, etc. Many thousands of scientists are employed there doing pure and applied research for specific purposes, purposes that I see as the negation of scientific pursuit: the development of new or improvement of old weapons of mass destruction. Among these thousands there may be some scientists who are motivated by considerations of national security. The vast majority, however, have no such motivation; in the past they were lured into this work by the siren call of rapid advancement and unlimited opportunity (according to Herbert York, the first director of the Livermore Laboratory). Theodore Taylor, one of the chief designers of the atom bomb in Los Alamos, said: ‘The most stimulating factor of all was simply the intense exhilaration that every scientist and engineer experiences when he or she has the freedom to explore completely new technical concepts and then bring them into reality.’ What is going on in these laboratories is not only a terrible waste of scientific endeavour but a perversion of the noble calling of science. It should not be tolerated.

The Nobel Laureate Hans Bethe, one of the most senior living physicists and one-time leader of the Manhattan Project, said: ‘Today we are rightly in an era of disarmament and dismantlement of nuclear weapons. But in some countries nuclear weapons development still continues. Whether and when the various Nations of the World can agree to stop this is uncertain. But individual scientists can still influence this process by withholding their skills. Accordingly, I call on all scientists in all countries to cease and desist from work creating, developing, improving and manufacturing further nuclear weapons – and, for that matter, other weapons of potential mass destruction such as chemical and biological weapons.’

I would like to see an endorsement of this call by the scientific community. I will go further and suggest that the scientific community should demand the elimination of nuclear weapons and, in the first instance, request the nuclear powers to abandon the policy of nuclear deterrence – an excuse for keeping nuclear arsenals indefinitely and, in essence, seeking to maintain peace by a balance of terror.

I am aware that by making these suggestions I am entering the domain of political controversy, but I am doing so without contrition. We are gathered here under the auspices of UNESCO, which has a clear mandate to abolish the culture of violence that characterized the 20th century and usher a culture of peace into the new millennium. But how can we talk about a culture of peace, if that peace is predicated on the existence of weapons of mass destruction? How can we persuade the young generation that they should cast aside the culture of violence, when they know that we are relying for peace on a balance of terror?

Let me, in conclusion, remind you that the theme of my speech was science and human values. The basic human value is life itself; the most important of human rights is the right to live. It is the duty of scientists to see to it that, through their work, life will not be put into peril, but will be made safe and its quality enhanced.



FORUM I

Science: achievements, shortcomings and challenges

WORLD
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SCIENCE

The nature of science

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What is the nature of science? Of course, it is virtually impossible to answer this question in a short text. The scientific endeavour is just too complex. But sketching some of the most salient features of scientific knowledge highlights one of the most distinctive characteristic features of science – its systematicity. This is not to say that other forms of knowledge are entirely unsystematic. For instance, if you want to know how many people are in a room, you would use a systematic procedure, namely counting, but this does not make you a scientist. However, scientific knowledge is typically more systematic than other forms of knowledge, and it expands its systematicity into new domains. The systematicity of scientific knowledge concerns more than one single aspect of science.

The systematicity of science

In this short essay, the systematic character of scientific knowledge is examined with respect to five features of science: how science describes, how science explains, how science establishes knowledge claims, how science expands knowledge and how science represents knowledge. These features of scientific knowledge are systematic, though not in exactly the same sense. But systematicity is always distinct from the purely accidental and random. Thus, my account of the nature of science will not really be an answer in terms of one single defining quality. Instead, the systematicity of science will concern all five of these features. Together, they articulate the specific nature of science, one of the most spectacular cultural achievements of humankind. In this essay, I will only deal with the natural sciences, but the analysis can easily be extended to cover the specific features of the social sciences and the humanities as well.

How science describes

Scientific descriptions represent a first aspect of the systematicity of scientific knowledge. In the historical natural sciences, like cosmology which describes the history of the universe or palaeontology which describes the history of life on the Earth, descriptions of particular events and processes are predominant. For example, palaeontologists attempt to describe the particular chain of events which led to the extinction of the dinosaurs some 60 million years ago. With respect to these particular descriptions, the historical natural sciences share much with other historical disciplines such as political history or art history. However, in the laboratory sciences, like solid state physics or protein chemistry, the situation is quite different. In these fields, scientists are not interested in a particular historical event or process, but always in groups of events or processes. Thus, while investigating a particular metal like copper, scientists are not interested in the behaviour of the particular piece of metal in their hands. They are interested in the behaviour of every piece of copper, or perhaps even more generally, in all metals. In other words, in the laboratory sciences, scientists aim for general descriptions, that is, descriptions that provide generalizations about a certain domain of phenomena, or the regularities holding in this domain. Making such general descriptions presupposes a classification appropriate to the respective phenomena. Similar phenomena must be grouped together, otherwise a generalized description is not possible. Here we find the first aspect of the systematicity of science. Science classifies phenomena in a systematic fashion. The systematic scientific ordering, or classification, of phenomena is mirrored by the large number of scientific disciplines and sub-disciplines, each of which deals with a particular domain of phenomena. For these domains, science aims at generalized descriptions which express the common nature of the phenomena in that respective domain.

Why does science aim at generalized descriptions? The reasons are the same as in everyday life and in engineering. Generalized descriptions can be used to predict, control, or explain phenomena of the same kind. Having general knowledge about how a certain material behaves enables one to use that material in a predictable way in the design of some apparatus. Knowing regularities of the weather enables one to predict its probable future course. But scientists want to dig deeper than a mere knowledge of these regularities that can be observed and described. Scientists want to understand the regularities of the world. This leads to the second aspect of the systematicity of science.

How science explains

Science typically creates theories. Theories serve many functions in science, and a complete description of all these functions is well beyond the limits of a short article. What is of main concern here is the explanatory, unificatory and predictive power of scientific theories. Typically, some domain of phenomena which is well described, but not really understood, finds an explanation through a scientific theory. Consider the planetary motions, for which fairly accurate mathematical descriptions have been known for quite a long time. But explaining why these motions take place as they do is a different kind of story. In the history of science, extremely diverse explanations have been given for these motions. For a long time, the most successful one had been that given by Isaac Newton. Newton's theory postulated a gravitational force as an explanatory device. This gravitational force is a typical ingredient of scientific theories as it is an entity that cannot be directly observed. In a sense, it is a speculative component of science. Because theories contain such speculative elements, they are risky, but I will return to this risk a little later. At this point, the systematic aspect of scientific theories is more important, namely their power to provide causal explanations which unify entire domains of phenomena. Thus, Newton's gravitational theory explained and unified such diverse phenomena as the free fall of apples, the motion of the planets and the occurrence of the tides. It systematically structured a vast domain of apparently diverse phenomena by providing a unified, quantitative, causal explanation: all of these phenomena are caused by gravitation.

Furthermore, with the use of theories, the predictive power of science increases tremendously. For example, many cultures had discovered the regularities in the motions of celestial objects, including knowledge of the temporal pattern of eclipses. On the basis of these generalized descriptions, it was possible to predict eclipses of the sun and the moon. But once these regularities were explained by an appropriate theory of gravitation, additional novel predictions became feasible; for instance, the prediction of the existence of a previously unknown planet. On the basis of the 20th century theory of gravitation – the general theory of relativity – even the existence of entirely novel entities has been predicted, among them black holes.

One particularly successful explanatory strategy is the use of reductionist explanations. These make systematic use of the fact that, very often, the behaviour of a particular system can be explained with reference to its constituent parts together with the laws governing their interactions. Large areas of science, such as solid state physics or quantum chemistry or molecular biology, rely on this sort of explanation. However, this explanatory strategy is only successful under two conditions: if the system's interaction with its environment can be neglected and if the internal organization of the system is not exceedingly complex. Evidently, systems that interact strongly with their environment cannot be explained with recourse to their component parts alone. Instead, approaches are needed that take these interactions into account. Additionally, complex systems may exhibit behaviour that is unexpected on the basis of knowledge of their component parts. In these systems, reductionist explanations may reach practical, or even in principle, limits.

How science establishes knowledge claims

The third aspect of science which exhibits systematicity is probably one of the most popular features of science. Science purports to provide a form of knowledge that is particularly reliable and trustworthy. What is the basis of this claim? The central insight, which science takes extremely seriously, is that human knowledge is constantly threatened by error. Error may arise as the result of mistakes, false assumptions, entrenched traditions, belief in authorities, superstition, wishful thinking, prejudice, bias and even fraud. Science is extremely careful and successful in detecting and eliminating all sorts of error. It is not that it is invariably successful, but it is the most systematic human enterprise in its attempt to eliminate error in the search for knowledge. Finding adequate generalized descriptions of some domain of phenomena is hard enough. It is all too easy to overgeneralize and fall prey to prejudices. But the real difficulty with error elimination concerns the fact that science strives for explanatory theories that contain entities which cannot be directly observed. How can the purely imagined be distinguished from an unobservable reality? How can science distinguish between a theory which uncovers some invisible mechanism that secretly governs some set of natural phenomena from a mere flight of fancy?

In this respect, the most outstanding characteristic feature of modern science is its use of experiment. Although experiments have been performed in various contexts across many cultures, the systematic use of experiment, as a means to test and confirm knowledge claims, is a unique feature of modern science. Of course, observation has been used by many other knowledge-seeking traditions, including the Western scholarly tradition out of which modern science emerged historically. But the systematic use of experiment to generate new knowledge and to test knowledge claims underwrites some of the outstanding features of modern science. First, the use of experiment allows scientists to test purported causal connections. Whereas, by observing, one can only see a temporal succession of events, by experimenting one can test whether the temporal succession is causal. Roughly speaking, this is accomplished by repeatedly producing one event and observing if the other event occurs thereafter. Second, experiments allow scientists to test claims about the existence and properties of postulated theoretical entities much more rigorously compared with observation alone. In an experiment, one can create a situation in which the postulated theoretical entities should behave in a particular manner. If these effects can indeed be observed, then one has indirect evidence for the existence and properties of the postulated entities. Finally, knowledge that has been experimentally tested can immediately be used practically. This is because applying knowledge technologically is basically the same series of physical actions as experimenting, but with different intentions. An experiment which tests a hypothesis about the causal connection between events A and B produces A then observes whether B occurs. Technologies which apply knowledge about the causal connection between A and B produce A in order to generate the desired effect B. In this way, the experimental character of scientific knowledge lies at the heart of its technological fertility.

The intellectual integrity of science crucially depends upon its willingness to assess its knowledge claims systematically. In mathematics, the most rigorous of all sciences, no statement that expresses more than a convention is accepted unless it is backed up by a proof. The natural sciences share a similar feature. Although one cannot prove statements from the natural sciences with mathematical certainty, no statement is accepted unless it is supported by a variety of empirical evidence and no statement is immune to revision or even refutation in light of empirical evidence. Systematically discovering the strengths and weaknesses of particular knowledge claims is one of the hallmarks of science. Experiments also play a crucial role in generating new knowledge, which brings me to the fourth aspect of the systematicity of science.

How science expands knowledge

From a sociological point of view, one of the most astonishing facts about science is its remarkably rapid growth over the course of several centuries. Science is entirely a dynamic enterprise. I think that this feature best distinguishes science from all other knowledge systems, past and present. Many other knowledge systems remained stable over centuries or even millennia, providing orientation to humankind. But science has managed to improve and expand its knowledge to an unprecedented degree. Of course, the growth of science depends on the availability of the appropriate material resources, but the mere availability of these resources does not explain why science strives towards, and succeeds in, improving and expanding its knowledge. Why does science always attempt to expand its knowledge and how does it manage to succeed so consistently?

First, science is driven by the ideal of systematically completing its knowledge. Scientists are not simply after some scattered facts about a certain domain. Ideally, they want to know everything about it. Physicists want to know all of the fundamental interactions of matter. Chemists want to understand the chemical bond completely. Biologists want to know everything about the human genome. Geologists want to have a complete grasp of the dynamics of the Earth’s crust. For this reason, scientists are typically aware of the gaps in their knowledge of a certain domain and they systematically try to fill these gaps. But how do they go about it?

The essence of science’s astonishing ability to expand our knowledge is the fact that the stock of already existing knowledge is systematically used in order to create new knowledge. Thus, every piece of newly gained knowledge provides additional resources for increasing knowledge further. Put succinctly, science is a self-amplifying process. To express this in cybernetic terms, there is a positive feedback loop such that the already existing knowledge enhances the production of new knowledge. This may be surprising to those who are more familiar with the traditional idea that science proceeds by applying the scientific method – understood as a set of rules which guarantee reliability of scientific knowledge and its progress. During the last few decades, close scrutiny of science has led to a move away from the idea of the scientific method. The procedures of science appear much more individually case-based. Productive scientific work is largely fuelled by existing scientific results which it takes as models then extends. Abstract rules or principles are not a major governing force. Science, especially fundamental science, is much more artful and playful than a strictly rule-governed procedure. Instead, the extension by analogy and metaphor from what is already known into unknown domains aids the creative process.

In addition, science exploits another body of knowledge in an extremely successful way. Science exploits technology. Of course, in the 20th century, technology is largely science based in the sense that many scientific results enter technological innovations. But it would be far from the truth to assume that technology is developed by a rather thoughtless, mechanical application of scientific results. On the contrary, engineers have their own creative traditions, quite distinct from the scientist's. But regardless of the extent to which a certain brand of technology is science based, science is always eager to exploit the latest technology. This is because of science's systematic use of experiment which I mentioned earlier. The import of new technology into science provides a whole host of opportunities for constructing new experiments or building more precise measuring instruments. In the second half of the 20th century, the use of computers and software has had innumerable applications in science. Completely new fields of research have emerged as the result of the possibility of electronic computing and many existing fields have been thoroughly revolutionized in the process. Again, we see a positive feedback process between science and technology. Science is used to create new technologies and new technologies are used to improve and extend scientific knowledge.

I have been talking about the intentional, planned expansion of scientific knowledge. But knowledge generation may also contain an element of chance, in particular with respect to surprising, novel knowledge. Paradoxical as it may sound, science is even systematic in exploiting chance for generating new insights. There are several aspects of this systematic use of chance. One aspect concerns so-called brute force approaches, where a vast number of cases are systematically searched, one by one, until an interesting case arises. An example is the search for pharmacologically active compounds by systematically examining a large number of chemical substances. A second way of forcing chance is by explorative experimentation into a comparatively unknown system. Bringing that system into different experimental conditions reveals its properties. A third way of exploiting chance for the generation of new knowledge is a by-product of experiments which aim at testing hypotheses. In these experiments, one has expectations about the outcome if the hypothesis is acceptable. Deviations from these expectations are readily noted. Such deviations may be due to the falsity of the hypothesis tested, but they may also be due to the falsity of some auxiliary hypothesis that was tacitly used, or even taken for granted, in the experimental setup. In the latter case, quite unexpected discoveries – chance discoveries as they are sometimes called – may be made. Scientific research procedures are such that these chances have a good chance of being noticed.

How science represents knowledge

The last aspect of science's systematicity that I will briefly discuss concerns the representation of scientific knowledge. The background idea is that knowledge itself is internally structured and that an adequate representation of this knowledge must take this internal structure into account. The results of science can and must be represented in an orderly, systematic fashion. Once again, a prime example is mathematics in which the systematic representation of knowledge is pushed to its extreme. But in the empirical sciences, important distinctions also have to be made with respect to the representations of knowledge: the general has to be distinguished from the particular, the well-established from the merely hypothetical, the descriptive from the theoretical, the logically dependent from the logically independent, etc. It is quite clear that the systematicity in representation is instrumental for other aspects of the systematicity of science. The systematic representation of existing knowledge may reveal gaps, errors or weaknesses of all sorts that might otherwise go unnoticed.

Drawbacks

Having reviewed those aspects which exhibit science's systematicity, let me now turn to those features that are, as a consequence of systematicity, drawbacks of science. There are two issues that seem to be most important in this context.

Specialization and fragmentation

The systematic character of scientific research leads to specialization. Specialization is an effect of systematically pursuing questions that present themselves in the course of research. Specialization is the price one has to pay for systematic, in-depth knowledge. There are also counter-tendencies in science that tend to overcome specialization. These tendencies are due to systematic attempts to unify science with the use of overarching theories, and by internally driven interdisciplinary research. But the main fact remains that scientific knowledge is quite fragmented due to specialization, at least in practice. There are various negative consequences of this kind of specialization and ensuing fragmentation. There is a communication problem between science and the public, between science and science policy, and within science between different disciplines, even between sub-disciplines in the same field. These communication difficulties give rise to a variety of problems. It is difficult for the public to understand what is going on in science; policy-makers have difficulties setting priorities; interdisciplinary research poses special challenges; and so on.

Over-extension of science

A second negative consequence of the systematic and comprehensive character of science is the seductive thought that science really addresses everything. But there are limits to science. I do not mean this in the trivial sense that there are limited resources for science. Rather, we must be prepared to accept that there are essential problems which do not admit of scientific solutions. In the century ahead, we will have to confront problems of drastically new proportions. Science will be an absolutely indispensable means for tackling the challenges ahead. But it would be unrealistic to expect that the solutions to all our problems will be provided by science by itself. Instead, we will have to make decisions concerning priorities, concerning values, and concerning conflicting priorities and values – and this both at local and global levels. In short, we will have to make decisions that are essentially political, not scientific. For these decisions, science can only be of subsidiary help. Of course, there is no substitute for the kind of help science, including the social sciences, can provide, especially in predicting the probable consequences of our decisions and actions. But the decisions will be ours and we will not be able to avoid painful responsibilities by delegating them to science.

Conclusion

Let me summarize this overview of the systematic character of science by quoting Albert Einstein, one of the greatest scientific minds of the 20th century. He claimed, ‘The whole of science is nothing more than a refinement of everyday thinking’. Replace ‘refinement’ with ‘systematization’ and you have the essence of this account.

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The universal value of fundamental science

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As Director of the Abdus Salam International Centre for Theoretical Physics (ICTP), I feel honoured at having been invited to address the World Conference on Science on the subject of basic science and its universal value.

The ICTP was conceived and shaped in 1964 by its founders Professors Abdus Salam and Paolo Budinich as both an intercultural bridge across political divides and a privileged instrument for international cooperation between the North and the South. It has become an extraordinary reality thanks to two umbrella United Nations organizations – the International Atomic Energy Agency (IAEA) in Vienna and UNESCO in Paris – and, most of all, to the generous interest expressed by the Italian Government and the people of Trieste.

I want here to relate the rich experience accumulated during these 35 years to the relevance and need for a solid infrastructure in basic sciences and a strong academic community in order to achieve full cultural and intellectual realization and economic development.

By the word ‘basic’, or ‘fundamental’, I intend to refer to that kind of research that seeks to increase our knowledge without aiming explicitly at a possible application and is therefore mainly driven by curiosity, internal consistency or the search for the ultimate consequences of previous results.

It is relevant to make this distinction in the context of this Conference because society relates differently to ‘basic’ and ‘applied’ science. The ethical aspects may also be radically different when possible far-reaching applications are difficult to foresee a priori.

A word of caution is in order on this terminology. I do not share the idea that there is a natural hierarchy in science that puts the study of the components of any system at a more basic level than the study of the organization and interactions of those same systems. Thus, for me, there is basic physics but also basic chemistry, biology and even behavioural sciences.

Modern science: its universal value

Science, as a collective venture spanning across generations, strongly depends on the social environment.

However, to different degrees, all societies have practised science, perhaps because the scientific method, despite its imposing name, is the simplest, most natural and universal way of acquiring knowledge. It is the extension, in a way that allows transmission of results, of an innate instinct to discover regularities in the world surrounding us. Our brains are pre-wired to build models where assumptions of regularity and constancy of the environment are assumed. They are also pre-wired to detect exceptions to the rule.

From the prehistoric hunter trying to uncover the traces of possible prey or the ancient Egyptian seeking to understand the cycles of the Nile floods, to the modern scientist, reasoning has always been the same. A farmer comes back home to discover mice have been inside the pantry. How does he or she decide where to put the traps? A scientist examining the energy spectrum in a nuclear reaction notices mass is missing. Something is going on undetected. How does he or she design a new detector to uncover what is happening?

In both situations, the attitude is the same. In both situations, different hypotheses will be proposed and discarded. The only difference lies in the amount of past experience brought to bear on the situations.

The scientific method, simply put, is timeless and universal. It is neither Northern nor Southern. It is the common heritage of all mankind. Abdus Salam revolted against the idea that modern science and its cosmo-vision is a Western product. The Arabs, Persians and Hindus played a crucial role in building and shaping science at times when Europe was still sleeping its mediaeval dream and we all owe to the Greeks and the Egyptians the basic foundations of science. We should also remember the Chinese contribution and how the Mayas seem to have followed parallel paths.

We must use the intercultural value of scientific language and its capacity to build bridges across cultural rifts. For example, in several parts of the world (e.g. the Middle East) a process of peace has started. We hope that programmes of scientific cooperation in those regions – such as the recent proposal to locate a synchrotron laboratory in the Middle East – will strengthen these movements towards peace. The ICTP stands committed to such goals and encourages other organizations to join us in these efforts.

What should be a cause for concern instead is that, in all historical civilizations, at some moment, progress in science slows and sometimes stops. Why this happened is an important question if we care for the future.

Let me offer a possible explanation. Knowledge in general, and scientific knowledge in particular, means power. Therefore, it is only natural that the dominant sectors of a society try to appropriate it and limit its access. They do that by ritualizing knowledge, hiding its experimental roots and above all discouraging further questioning. They may even create a kind of 'clergy' in charge of preserving the 'truth' but who in practice shield it from further scrutiny. The dominant sectors in power ultimately become content with this stasis.

Today science seems unstoppable. However, we should not underestimate the new dangers that could arise if more stringent intellectual property rights are approved allowing new types of appropriation. At this moment, when technological progress is making dissemination of information so easy, it would be tragic to create new obstacles in the way of accessing information. It could, once again, leave developing countries outside the common endeavour of creating knowledge. Of course, in the long run, all countries will suffer.

Knowledge/information is that special kind of resource that cannot be exhausted when we share it. We lose nothing if we share our knowledge. Most probably we enrich ourselves. Society would draw maximum benefit if everybody had free access to every bit of information.

The threat comes from the otherwise valid concern that creators need incentives which some suggest should be derived from copyright. Independently of the ethical objections that can arise from preventing access to those who are not able to pay, it is in practice extremely difficult to correctly assign copyright to basic science results and it is impractical and costly to guarantee excludability for this type of knowledge.

The Abdus Salam ICTP would therefore like to propose that (at least basic) science results be declared an international public good and that their access be made free for everybody. We should defend science as our common endeavour.

The economic dynamics of basic science research

There is a related dilemma when decisions have to be taken concerning basic science funding. The private sector is not happy with the idea of paying for something that could benefit a competitor. A private firm could support basic research either if it enjoys a monopolistic situation or if it estimates that the time lag between the basic research result and its application is so short that it can reasonably expect to reap sufficient benefits from being the first to know the result (this is the case today with genetics research).

Even then it is a theorem in economics dynamics that the private sector alone would strongly under-invest in basic research. This is due to the fact that, in any case, the social returns are larger than the benefits a private investor can appropriate. An analysis of social returns on investments in academic research in the USA (which are either in basic science or share the same problems of appropriability) deserves quoting. In the period 1982-1985, 76 firms belonging to seven industries identified new products that could not have been developed at all or would have suffered substantial delay in the absence of recent academic research (Table 1). Those products accounted for about US$ 24 billion of sales in 1985 alone. The mean time lag between the successful research result and the appearance of the product in the market was calculated to be seven years. Taking into account total spending on research and development (R&D) in the academic sector and other expenses needed to generate the final product (industrial R&D, plant and equipment and start-up activities), this study (Mansfield 1991, 1992) estimates a social rate of return that exceeds 20%. This is very high and it is still an underestimate because it does not include, for instance, the educational value of research.

Another analysis worth quoting is the work by Boskin and Lau (1990, 1992) on the percentage of economic growth that can be assigned to R&D investment. These authors pooled growth data from the G7 countries (to which they later added data from East Asian emerging countries) into the same aggregate production function. This is a strong assumption but with it they could then isolate what fraction of economic growth was due to technical innovation by using regression of the residual on R&D investment. Two interesting findings deserve consideration.

- They analysed the rapid growth of some East Asian countries that have invested little in R&D and found that, in fact, they have compensated for it with huge capital investments.
- They found a positive correlation between the size of the residual growth and the R&D investment.

Table 1. **Percentage of new products and processes based on recent academic research, seven industries, USA, 1975-1985**

	Percentage that could not have been developed (without substantial delay) in the absence of recent academic research		Percentage that were developed with substantial aid from recent academic research	
Industry	Products	Processes	Products	Processes
Information processing	11	11	17	16
Electronics	6	3	3	4
Chemicals	4	2	4	4
Instruments	16	2	5	1
Pharmaceuticals	27	29	17	8
Metals	13	12	9	9
Petroleum	1	1	1	1
Industry mean	11	9	8	6

Source: Mansfield (1991)

While this second analysis refers to all investments in R&D, the first one is more restrictive and more relevant to the subject of this talk. If we add that private rates of return come out typically a factor of two or three smaller than the rates of return for society, the moral is simple: the public sector should take on the burden of the necessary investment in basic science research, either directly or indirectly (by tax incentives) leaving, if they wish to do so, the technological applications to the private sector.

The second analysis indicates that countries are able to appropriate at least partially the economic returns on science (because the technical growth is correlated with R&D investment). However, again it is not clear to what extent. If countries conclude that they can exploit the investment made by others in basic science research, this would again lead to global under-investment.

Table 2. **Research and development effort in North America (1996)**

USA	
Total R&D spending	US$ 184 billion
Percentage of GDP	2.5%
R&D performed by academic or non-profit institutions	US$ 34 billion
Percentage of GDP	0.46%
Basic research spending	US$ 30 billion
Percentage of GDP	0.40%
Canada	
R&D spending	US$ 10.2 billion
Percentage of GDP	1.6%
R&D performed by academic and non-profit institutions	US$ 2.4 billion
Percentage of GDP	0.38%

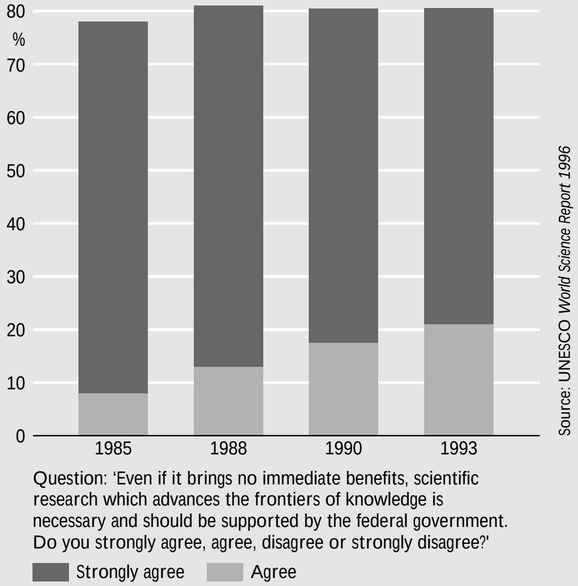
Source: UNESCO, *World Science Report 1998*

Therefore, in parallel to the proposal that basic scientific knowledge be declared an international public good, every country should pledge minimum support to basic science at a level that is commensurate with its resources.

In order to have at least some idea of how much investment in basic science research would be reasonable, I quote here some figures from UNESCO's *World Science Report 1998* (Table 2).

Developing countries should aim at a higher rate of investment because they have to build infrastructure. As a consequence, a pledge for a rate similar to that of Canada or the USA is not at all a sacrifice.

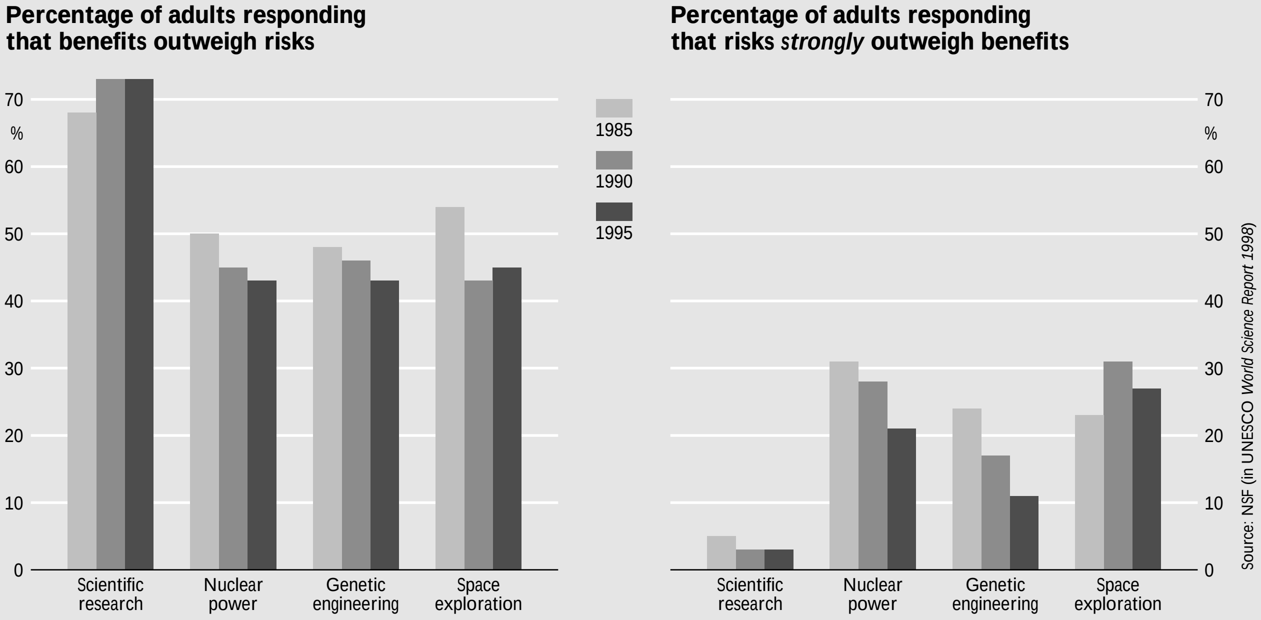
Figure 1. **Attitudes towards federal support for basic scientific research, 1985-1993**



Question: 'Even if it brings no immediate benefits, scientific research which advances the frontiers of knowledge is necessary and should be supported by the federal government. Do you strongly agree, agree, disagree or strongly disagree?'

Source: UNESCO *World Science Report 1996*

Figure 2. **US public assessment of research and technologies, 1985-1995**



Source: NSF (in UNESCO *World Science Report 1998*)

Public perception of science and basic science

It is interesting to observe that all studies show that the positive perception of pure science remains intact despite the growth of those who declared themselves concerned and worried by the possible applications of science. Thus, the polls conducted in the USA (Figure 1) indicate a high level of support for, and trust in, pure research that does not extend to applied research.

Our experience indicates that pure science is also very popular in developing countries although, given the urgency of other problems, this does not necessarily translate into the political will to financially support it. (Compare instead the data again from the USA, Figure 2.) In the next section we try to show the absolute necessity for strong investment in developing countries and the role that international cooperation can play.

Why basic science in developing countries?

If the opportunity of investing in basic science is questioned in rich countries because they assume that they can free-ride on the results obtained in another country, the dilemma becomes dramatic in developing countries. Here well-intentioned decision-makers may recognize the importance of basic sciences, but worry whether they can afford to invest in them given the depth of their immediate economic and social problems.

International aid agencies have been particularly sensitive to these arguments so that some of them (e.g. the current Fifth Framework Programme of the European Commission) explicitly rule out any support to basic science.

However, the consequences for the developing world, especially the least developed countries, could be disastrous. Here I am speaking on behalf of thousands of scientists from the Third World who bring their experience to the ICTP.

One cannot forget the real suffering faced by millions of people in the developing world; nor can anyone suggest that nations should postpone those urgent immediate steps necessary to improve the economic and social well-being of their people. However, if the effort to solve immediate problems prevents the build-up of indigenous know-how, then the problems of today will be the problems of tomorrow. More specifically, and as an example of possible plans of action, when international agencies finance goal-oriented projects, they should simultaneously help in building up a solid scientific establishment so that knowledge is effectively transferred.

Applied research is of direct relevance and importance, but it requires:

- a critical mass in several basic sciences;
- continuity of management and funding;
- either international collaboration or local expertise.

A good foundation in basic sciences is therefore an indispensable ingredient. Basic scientists will educate young researchers who will profit from applied research projects. In many cases in developing countries, basic scientists have gone into applied research programmes. Last but not least, basic science, being from the start international and academic in character, is subject to that tight and transparent quality control that every society is entitled to expect.

This problem of quality control has been generally overlooked, though the consequences of such an attitude could seriously jeopardize valid efforts to build up a scientific infrastructure. In general, the problem can be rephrased in the following way: how can non-experts (the public in general, government officials) judge the quality of an expert? Or equivalently, in a world where solutions to problems increasingly involve scientific knowledge, how can public officials and citizens determine which experts to trust when there are competing opinions? Issues that call for a science-based solution normally elicit competing proposals that rely on powerful lobbies to gain support – and ultimately funding – for the different strategies. Without access to university-based scientists capable of assessing the merits of each proposal, public officials and citizens alike will be at the mercy of those who have vested interests in the proposals that they are presenting.

As normally happens in developed countries, the practical solution relies on strong academic institutions and, more specifically, on the fact that scientists working in basic research can be objectively evaluated. This is because of the free dissemination of basic scientific knowledge and because the open problems are shared and known by all those working in the same discipline. Such an assessment will never be exact but even if approximate it can be extremely useful.

For applied research, this information is more difficult to obtain. First of all, publications are less relevant. Second, experts are not necessarily organized into disciplines. Third, by definition, the problems they address are unique events that do not reproduce exactly.

The North has long called on its basic scientists to serve as impartial judges for assessing controversial science and technology issues of vital national concern. An interesting relatively recent example was the calling of Richard Feynman, Nobel Laureate for Theoretical Physics, to assess the causes of the Challenger Shuttle disaster. The story is known but it shows how society used his name and impeccable credentials of impartiality to recreate the trust that had been torn between NASA and the public.

In short, well-trained basic scientists have the power to bridge the gap between scientific experts and the public in ways that make science-based development possible.

International cooperation on basic research capacity-building

There are profound ethical reasons but also practical, economic reasons to make a case for richer countries to aid poorer ones to build up human capacity in basic sciences.

The first reason, and perhaps the most important one, is the deep moral conviction that, in the big adventure of exploring nature, no cultural group, no nation should be left aside. It is an ethical-political issue. Ethical because it has to do with equal dignity for all the people of the world. Political because it stresses the ultimate unity of our planet.

We would like to suggest that this Conference recognizes participation in scientific research projects as one of the fundamental human rights of each individual, as the natural continuation of the already recognized right to higher education and as a part of the cultural rights indispensable for dignity and the free development of the personality, as discussed in Articles 22 and 26 of the *Universal Declaration on Human Rights*.

But there are other more practical reasons that suggest that it is in the interest of rich countries to act in this way. With globalization, problems are also becoming global. Environmental deterioration is one example but there are others such as natural resources management and preventive health care programmes. We have already argued that capacity-building in basic sciences is an important preliminary step towards creating networks of experts capable of addressing these global programmes.

On 15 and 16 June 1995, an International Conference on Donor Support to Development-Oriented Research in the Basic Sciences was held at Uppsala University, Sweden[1]. Among the convenors, there were several agencies with pluriannual experience in basic science cooperation. They included: International Programme for Physical Sciences (IPPS), Uppsala, Sweden; International Foundation for Science (IFS), Uppsala, Sweden; Third World Academy of Sciences (TWAS), Trieste, Italy; International Centre for Genetic Engineering and Biotechnology (ICGEB), Trieste, Italy and New Delhi, India; Swedish International Development Cooperation Agency (SIDA), Sweden; Institut français de recherche scientifique pour le développement en coopération (ORSTOM), Bondy, France. The conclusions are worth quoting.

- A foundation in the basic sciences is essential for all research in the applied sciences and for long-term development.
- Adequate funding for the basic sciences from domestic support and external aid programmes is necessary.

The measures proposed were:

- capacity-building in basic sciences;
- support for research and higher education in the basic sciences. In particular, donor support to applied projects should include grants to research and higher education in basic sciences.

The World Bank has recently introduced its own programme and proposes the Millennium Centres project with special emphasis on excellence. During this Conference the French Government has pledged to increase its support to the Centre International de Mathématiques Pures et Appliquées, Nice, with whom the ICTP has many programmes in common in Africa. We also salute the steady progress of the Asia-Pacific Centre for Theoretical Physics in the Republic of Korea, which may count on the strong support of Japan and Korea and which could become an associated centre of UNESCO. And last but not least, the continual and still growing support of the Italian Government for the Trieste Centres.

I am confident that the time has come when we do not have to argue any longer whether basic research is a luxury that developing countries cannot afford.

Note

1. This meeting was associated with the World Conference on Science. The meeting report may be consulted at: http://www.unesco.org/science/wcs/meetings/eur_uppsala_95.htm

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FORUM I KEYNOTE SPEECH

The scientific approach to complex systems

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This paper will focus on specific technical aspects of our emerging understanding of complexity. It will include elements of pure science and will end by briefly setting out some of the implications that this work has for policy formation and public awareness, public confidence and the use of scientific advice in policy-making.

First we must consider whether the scientific approach provides understanding and help in approaching complex systems. The short answer is 'yes, with reservations'.

For the last several hundred thousand years, humans have thought about simple and complex aspects of the world around them. The origins of science, that is, the pre-scientific thinking in prayers, magic or sometimes codified fatalism, paved the way for the scientific revolution of the Enlightenment in the 17th and 18th centuries. Since that time, in an ever-accelerating way, we have come to understand much of the world around us and to change the world with that understanding. The last 50 years have seen more advances than in all our previous history.

Fifty years ago the average life expectancy at birth on this planet was 46 years. Today, it is 64 years. Fifty years ago, however, the difference in life expectancy at birth for a typical First World birth compared with a typical Third World birth was 26 years. Today the difference is only 12 years. And that has come about as a result of using scientific methods to bring about advances in medicine and food production.

The hope has been that essentially the same methods can be expanded to encompass ever more complex systems. This hope is important because, as is said in the US National Science Foundation's programme on complexity, humanity depends upon increasingly complex systems for food, fibre, breathable air and other vital natural resources. Such systems establish the parameters for, and the environments in which occur, all human economic and social interactions.

It is therefore important to recognize that relatively recent advances actually do change the way we must think in very fundamental ways in relation to many complex systems. The 'traditional' Newtonian view of the world said the world does obey rules. The world is not governed by gods and demons. The world is an orderly place. When the rules are relatively simple, it is possible to make predictions and to fully understand. The Newtonian paradigm says when the rules are very complicated, as in a roulette wheel, with many things happening, then it is more difficult to make predictions.

The emerging message of disciplines such as 'chaos' and 'complexity' is that the simplest rules which can be imagined, with nothing random or probabilistic in them, can generate behaviour as complicated as anything which can be imagined. Such behaviour is not merely complicated, but so sensitive to the initial conditions that long-term prediction is effectively impossible – and therefore the end, in many ways, of the Newtonian dream.

For example, a sequence can be generated if a number between 0 and 1 is multiplied by 1 minus the number and then multiplied by a rigidly predetermined constant to produce the next number. The Newtonian intuition says that should give you a stable steady point eventually: and that is true if the constant is in a certain range. But, as that non-linear equation is the thing that says the next x is not just a multiple of x but has some feedback (1 minus x), then, as the expansion and contraction of the non-linear relation – increasing at low density, decreasing at high density – becomes more pronounced, that simple thing may generate regular cycles (which still causes no problem with prediction) or it can generate a sequence of numbers that look utterly random.

It could be argued that the relation could be calculated because, since it is not random, it is therefore predictable. But the really key point is that in the 'chaotic region' the tiny errors that occur in the starting point lead very rapidly to completely different trajectories. For example, if the starting point is 3.9 x (1 – x), and x = 0.3, a particular trajectory will result. But if a very small error, as little as 0.1%, is made, within around 10 time steps an utterly different trajectory will result. This seriously undercuts the notion that complex systems are like simple systems with big computers.

Nature can produce very complicated behaviour from very simple rules. A good illustration can be produced by plotting the movements of a child on a swing being pushed by a parent – effectively a forced frictionless pendulum. If the parameters are right this will generate regular clockwork. For other values of the parameters the child may end up going round clockwise or anti-clockwise depending on the initial conditions. There will also be two other distinguishable orbits. If on the imaginary graph the horizontal axis plots the initial angle of the child, and on the vertical axis the initial angular speed, Newtonian intuition says if an initial point for the clockwise endpoint is coloured red and for the anti-clockwise endpoint blue, there will be a broad area of blue and red which will, in general, enable prediction. However, in reality, a hugely complicated, ultimately fractal array of end states will be seen. Indeed, depending on the initial angle at the initial pushing speed, totally different endpoints will result. Moreover, magnification of the results to achieve ever finer detail will demonstrate beyond doubt that the outcome of that piece of clockwork cannot be predicted.

Other examples are found in the very simple rules governing the dynamics of the interplay between HIV and immune system cells. It is this interplay which generates the huge complexity of different strains and helps explain why there are such long, variable and unpredictable intervals between infection with HIV and the onset of AIDS.

The basic message is that these new approaches teach us that complex systems governed by simple rules can form complex structures, which vary widely on different spatial scales depending on the size of the system, and which vary greatly on different time scales depending on the temporal scale of investigation. And most importantly, very often the probability distributions of events are not normal bell-shaped distributions, but distributions where so-called exceptional events are not that rare, but are much more common than intuition would suggest.

Conversely, since we know that very simple rules can result in very complicated behaviour, it must also be true that sometimes very complicated behaviour can originate from relatively simple rules. This offers new approaches to many areas of science. For example, data on the Canadian lynx and the snowshoe hare have oscillated about a 10-year cycle for over 100 years. There is much academic quarrel about what drives that cycle. Is it a predator-prey cycle? Is it the hare driven by food or a disease, with the lynx responding to this? Some 20 years ago I suggested that this is not a sensible way of thinking about it, and probably you need at least two variables to explain it. Nils Stenseth, at the University of Oslo, has used the new methods based on complex systems to deduce that you need at least two variables to understand the hare, but only one variable to understand the lynx. We don't, however, know what the variables are.

Some final thoughts on these issues. Galileo, articulating the triumphalist scientific dream, said, essentially, that the grand book of nature is written in the language of mathematics where the characters are triangles, circles and other geometric objects. And there is actually a deep piece of mathematics there that relates geometry to dynamics.

I also believe that the grand book is essentially written in mathematics; and that mathematics is just a way of thinking clearly. However, Galileo was wrong about the simple world of Euclidean geometry and triangles. We now understand that the real world has many fractal objects, objects with finite area and infinite perimeter, objects with fractional dimensions. The world of Galileo had simple, stable points, stable cycles. The world of chaos has in the simplest instance strange attractors, curious deterministic but unpredictable orbits. It is a richer and more interesting world, and it has been summarized and interpreted poetically by Tom Stoppard in his play Arcadia where he puts these words into the mouth of a young post-graduate student working on chaotic cycles in grouse:

'The unpredictable and the predetermined unfold together to make everything the way it is. It is how nature creates itself, on every scale, the snowflake and the snowstorm. It makes me so happy. To be at the beginning again, knowing almost nothing. People were talking about the end of physics. Relativity and quantum looked as if they were going to clean out the whole problem between them. A theory of everything. But they only explain the very big and the very small. The universe, the elementary particles. The ordinary sized stuff, which is our lives, the things people write poetry about – clouds – daffodils – waterfalls – and what happens in a cup of coffee when the cream goes in – are full of mystery; as mysterious to us as the heavens were to the Greeks. We are better at predicting events at the edge of the galaxy or inside the nucleus of an atom than whether it'll rain on auntie's garden party three Sundays from now. Because the problem turns out to be different. We can't even predict the next drip from a dripping tap when it gets irregular. Each drip sets up the conditions for the next, the smallest variation blows prediction apart, and the weather is unpredictable the same way, will always be unpredictable. When you push the numbers through the computer you can see it on the screen. The future is disorder. A door like this has cracked open five or six times since we got up on our hind legs. It's the best possible time to be alive, when almost everything you thought you knew is wrong.'

All this makes for enormous problems, in dealing, as we must, with complexity in a post-Newtonian world. It makes for a huge problem in science advice and policy-making.

The 20th century draws to a close with many good things having happened but many unintended consequences from our understanding of the world: human-created climate change, desertification, and so on. These problems are but the shadow on the wall compared to the problems that will be upon us in the next century as we begin to unravel the molecular machinery of life.

Current debates about genetically modified crops, cloning, xenotransplantation are but the beginning. We cannot imagine the problems that will arise as we increasingly have the capacity to change ourselves. And particularly in truly democratic countries, the dialogue between government, the policy-makers and the governed, the populace who must have confidence, is going to be a dialogue about questions which are inherently scientific. They are constrained by scientific realities, they are governed by scientific complexities, and we are only beginning to learn how to manage that dialogue.

The answer is not simply more education. Numerous public studies show that the countries that understand science best – Denmark always comes first in these international comparisons – are the countries that distrust science most. That is how it should be. The more you understand, the more you understand the complexities and the Faustian nature of the bargain. The answer must be that government conducts its dialogue with the public in an open, consultative way.

The United Kingdom government now has formal protocols for science advice and policy-making backed by a cabinet committee. They assert: consult widely, involve people that are expert in areas other than the area in question to get a wide range of perspectives, and then publish the results. But this has a cost. It is much more comfortable to obey the old mode of saying this is what the scientists told us, trust us. But it does not work any more, and as democracy increasingly spreads to every country in the world, this approach will become less and less acceptable.

There is a lesson in all of this which is encapsulated in words that were put into Galileo's mouth by Bertolt Brecht in his play about Galileo: 'The aim of science is not to open a door to infinite wisdom, but to put a limit to infinite error.'

FORUM I KEYNOTE SPEECH

International cooperation in science

Julia Marton-Lefèvre
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I am particularly proud that this important Conference is being held in Hungary, the country of my birth. Hungary is a most fitting host for such a meeting for, in spite of its small population and turbulent history, it has always been recognized as a country that has nurtured good science, with an impressive number of Nobel Laureates (one measure of excellence) and other world-class scientists, especially in mathematics, physics, chemistry and economics.

Allow me to celebrate our host country by reminding you of only a few brilliant Hungarians who made major contributions to knowledge in this century:

- Joseph Galamb (1881-1955), who designed the famous Ford Model T;
- Theodore von Kármán (1881-1963), father of modern aerodynamics;
- Albert Szent-Györgyi (1893-1986), who was awarded the Nobel Prize in 1937 for his identification of vitamin C from the famous Hungarian paprika;
- Leo Szilárd (1898-1964), who discovered the nuclear chain reaction and proved the case for neutron multiplication for uranium fission; and who drafted the letter, signed by Einstein and sent to Roosevelt, which persuaded the President to launch the Manhattan Project;
- Zoltán Bay (1900-1992) recorded the first radar echoes from the Moon, marking the beginning of radio astronomy. He also developed the new international meter standard based on the speed of light;
- Dennis Gábor (1900-1979), whose 1971 Nobel Prize was for his invention and development of the holographic method;
- Eugene Wigner (1902-1995), whose 1963 Nobel Prize in physics was for his contribution to the theory of the atomic nucleus and the elementary particles;
- John von Neumann (1903-1957), father of modern computers and of games theory;
- Thomas Balogh (1906-1981), economist at Oxford University and important adviser to the British Government which gave him a peerage;
- Nicholas Káldor (1908-1984), economist at Cambridge University and influential adviser to the British Government which gave him a peerage;
- Edward Teller (1908-), who was among the first to study thermonuclear reactions and played a key role in producing the American hydrogen bomb. He was the first chairman of the Committee for the Safety of Nuclear Reactors established after the Second World War;
- Paul Erdös (1913-1996), mathematician, recipient of the Wolf Prize;
- John C. Harsányi (1920-), who was awarded the 1994 Nobel Prize in economics, which laid the groundwork for the fast-developing research area, the economics of information;
- John Kemény (1926-1996), mathematician, computer scientist and president of Dartmouth College;
- George A. Olah (1927-), who was awarded the 1994 Nobel Prize in chemistry for his contribution to carbocation chemistry. Unleaded gasoline is one of his most recognized achievements;
- Ferenc Pavlics (1928-), the chief engineer of the team that designed and produced the Lunar Roving Vehicle (LRV), dubbed ‘moon buggy’, for the Apollo Program.

I could list many others, such as Andrew Grove, George Soros, Arthur Koestler, Elie Wiesel, all of Hungarian origin and all having made important contributions to knowledge and to making our world a better place.

I wonder how the social scientists among us would explain the ‘Hungarian phenomenon’? I am not sure if I fully agree with Leo Szilárd, Francis Crick or Leon Lederman in accepting that we Hungarians are ‘infiltrators from Mars’. Surely there must be a more earthly explanation. Perhaps it is due to the uniqueness and complexities of the Hungarian language, or to the precarious geopolitical position of this small country which has forced its people to be ready for the unexpected at all times. I will always remember how Lars (Lászlo) Ernster, the late respected biochemist, once a secretary-general of ICSU, explained what a good combination Swedes and Hungarians make: the Hungarians always ready to face a sudden, unexpected enemy and the Swedes, with their long winters, able to take time to think strategically about their next move.

The role models, widely cited in this small country, of the past giants in science, technology, and culture have also contributed to this Hungarian phenomenon, as has, perhaps, the heavy use of paprika with its vitamin C in the daily Hungarian diet. Credit must also be given to the education system which has always been selective and demanding, stressing the highest performance at all levels and by all its students. I have my own parents to look to as role models in this. Both are in their late eighties, both have their PhDs and both can still recall the dates of most major world historic events and recite Hungarian, German and French poetry by heart.

Now let me turn to the important and yet often elusive topic of international cooperation in science. The title of this presentation already tells you that one cannot take credit for any accomplishments or failures in international science on one’s own. All the words ‘international’, ‘cooperation’ and ‘science’ imply working as a part of a team. Thus, I accepted to give this address as a member of that team, having begun my international career at the United Nations Environment Programme (UNEP) and UNESCO, then having spent many years at ICSU and now building a new programme in international cooperation, about which I will tell you a little before I conclude.

The huge network of scientists and science policy-makers who contribute to the work of the two principal sponsors of this Conference, ICSU and UNESCO, as well as the numerous partner organizations with which they cooperate, are the principal institutional actors in international science. The objective of this network has been, for 100 years, ‘to encourage scientific cooperation for the benefit of humanity’.

The President of ICSU, when I first joined that organization, was the late F. Bruno Straub, the eminent Hungarian biochemist, who later became President of Hungary. He was succeeded at ICSU, some years later, by the late Sir John Kendrew, British Nobel Laureate, who also had a deep interest in music and in science in developing countries. These two eminent scientists, mentors of my younger years, are appropriate examples of the stress I will place in this address on the need for science and scientists to be involved in society, as scientists and as public servants. Professor Hámori, who is both a distinguished scientist and government minister, is also an eminent example of this and I could cite many more just from this audience. I hope one lesson we will take away from this Conference will be that the world needs more such scientists involved in public life.

In the time allotted to me, I want to comment on a number of issues. First, I will say a few words about the history of international science; then I will refer to the case of international cooperation in the environment; and finally I will outline some challenges for the future and make recommendations for action.

Brief history of international science

I will not go back as far as Copernicus in this talk, nor remind you of the contributions made by thinkers in far corners of the world for Copernicus to come to his revolutionary conclusions; nor will I dwell here on the importance of Chinese astronomical records and Indian mathematics, or on the contributions of alchemists to chemistry, or on the significance of Galileo’s, Newton’s, Linnaeus’ and Darwin’s theories and discoveries. I will also not speculate which was the century in which scientific progress was the most remarkable.

I will concentrate on the century which we are about to leave behind and remind you of some of the major actors in international science. In some ways calling science ‘international’ is hardly necessary – by definition it is international. Think of any discipline of science and imagine it without the free and open communication between scholars from other parts of the world. This is certainly true of the natural sciences, and hopefully increasingly so in the social sciences and, even more importantly, between the social and the natural sciences. Individual scientists are the key and natural actors in international science and they were communicating, travelling and meeting already in the 19th century and even earlier.

However, in the last year of the 19th century, a group of scientists wisely decided that the pursuit of science would be facilitated by the establishment of an organization that would be truly international and devoted to the advancement of science through international activities. This led to the creation of the International Association of Academies, with 10 founding members. The objective of the association, set up in 1899 (just 100 years ago) was to ‘initiate and otherwise to promote scientific undertakings of general interest, and to facilitate scientific intercourse between different countries’. A few years after the establishment of the IAA there were already concrete signs of the kind of action which justified it in, for example, the creation of a world system of seismological and geological observation stations.

After the outbreak of the First World War, the IAA lost its energy and it was not until a conference in Paris in 1918 that a new organization was created: the International Research Council, with only five academy members, none from the central powers nor from countries which remained neutral during the war. Thus, the new body was far from respecting the tenets of the international or universal nature of science. The IRC remained in existence until 1931 and had as one of its goals the initiation or the 'formation of international Associations or Unions deemed to be useful to the progress of science'. The fact that the IRC excluded many countries led to its demise and in 1931 it was dissolved and the International Council of Scientific Unions, ICSU, was born. The new name was meant to recognize the non-political nature of science as represented by the independent scientific strength of the unions. At the formation of ICSU there were 40 national members and 8 scientific union members. Last year ICSU's name was changed slightly to reflect its reality even better. ICSU is now known as the International Council for Science, although the acronym of ICSU has been kept to remind us of its long history. Today ICSU's membership comprises over 90 national scientific members, 25 international scientific unions and some 60 interdisciplinary bodies and joint undertakings with other organizations.

The strength of the international scientific community, as represented by ICSU, is based on a clear adherence to a non-political agenda in which only science can determine the programme, and to a strict adherence to the principles of the universality of science. Thus, since its establishment in 1931, having learned the lessons of its more politicized predecessor, the IRC, ICSU has 'vigorously pursued a policy of non-discrimination, affirming the rights and freedom of scientists throughout the world to engage in international scientific activity without regard to such factors as citizenship, religion, creed, political stance, ethnic origin, race, colour, language, age or sex'.

It is regrettable that the social sciences and even the engineering and medical sciences are not better represented in ICSU. The reasons for this are understandable, especially from a historical perspective. The time has come, however, to seriously revisit this matter.

Although ICSU was well on its way to carrying out its mission of promoting international scientific cooperation before the United Nations system was established, it would be impossible to describe international science without referring to United Nations bodies, most notably to UNESCO. UNESCO, being the only United Nations body with the word 'science' in its title, has made a number of contributions to the development of international scientific cooperation in the second half of the 20th century. Our meeting here in Budapest is clearly an important undertaking.

International cooperation in science: the case of the environment

I will illustrate how international cooperation works by referring to environmental research, which exemplifies scientists' interest in international collaboration and the capacity found in both the non-governmental and governmental structure to create productive opportunities for joint efforts.

Scientists have been involved in studies of the environment or the earth system for a very long time and in the mid-1950s, in response to pressures from governments and the scientific community, ICSU launched the important International Geophysical Year, whose political and scientific legacy is still with us. The IGY may be called one of the early 'mega-science' projects. It was after the IGY that scientists felt confident enough to initiate programmes on a larger and more international scale than ever before.

In the late 1950s and the 1960s, therefore, a number of important international scientific programmes, which are still in existence, were set up, devoted to Antarctic research, oceanography, hydrology, and to the scientific problems of the environment.

Starting in 1964, the decade-long International Biological Programme (IBP) began and left its important contribution to the ecological sciences. The IBP was the direct predecessor of UNESCO's Man and the Biosphere Programme (MAB).

In the 1970s, the International Geological Correlation Programme (IGCP) was established by the ICSU Union on the Geological Sciences and UNESCO; and the Global Atmospheric Research Programme (GARP), the first undertaking in full partnership with another United Nations body, the World Meteorological Organization (WMO), was begun to study the transient behaviour of the atmosphere and the factors that would lead to better understanding of the physical basis for climate. In that decade, the scientific community also became much involved in the 1972 Conference on the Human Environment, held in Stockholm.

Early in the 1980s the International Biosciences Networks (IBN), jointly sponsored by ICSU and UNESCO, came into being to assist developing countries gain access to the latest findings in the biological sciences. ICSU and UNESCO both increased their activities in science and technology for development in this decade, thus involving scientists from more parts of the world in international collaboration.

The 1980s also saw the fruition of the work of SCOPE (ICSU's Scientific Committee on Problems of the Environment) and collaborating United Nations bodies on the biogeochemical cycles, especially the carbon cycle, which helped turn political attention to the greenhouse effect. Other excellent examples of international cooperation aimed at increased understanding of the earth system include the notable work of UNESCO, WMO and ICSU in the hydrological sciences and in oceanography.

The World Climate Research Programme (WCRP), sponsored first by ICSU and WMO and later also by the Intergovernmental Oceanographic Commission (IOC) of UNESCO, succeeded GARP to study the physical climate system. The International Geosphere-Biosphere Programme (IGBP), a study of global change, was set up by the entire ICSU family in 1986 to describe and understand the interactive processes that regulate the total earth system and the manner in which these are influenced by human activities.

In the 1990s a number of global observing systems were also launched as a result of a common concern by governments and scientists of the need to keep the earth system in its totality under continuous observation. These observing systems – GCOS (on climate), GOOS (on the world's oceans) and GTOS (terrestrial observations) – are jointly sponsored by a number of United Nations bodies, including UNESCO, and the single non-governmental partner ICSU.

The international research programme on the structure and function of biological diversity, DIVERSITAS, involving various ICSU bodies and UNESCO, was set up early in the 1990s, whereas the study of the interactions between human society and its environment on a planetary scale, the International Human Dimensions Programme on Global Environmental Change (IHDP), was established jointly by ICSU and the International Social Sciences Council only in 1996.

With this vast number of important global programmes as a part of the development of international science, it was natural for ICSU to become a full partner, with five United Nations bodies, in the organization of the Second World Climate Conference in 1990, then to accept the challenge to move the international scientific effort to a more noticeable policy level by participating in the preparation of the 1992 United Nations Conference on Environment and Development, the Earth Summit, held in Rio de Janeiro, Brazil. A group of organizations led by ICSU put together a very ambitious conference just a year before Rio, on An Agenda of Science for Environment and Development into the 21st Century: AGENDA 21. This was the first time that scientists: physical, chemical, biological, medical and social, with engineers, came together to contribute their knowledge to the issues of grave common concern. The outcome provided an important input to the United Nations conference in Rio including the chapter on Science for Environment and Development in Agenda 21. It also resulted in a solemn 'commitment on the part of the international scientific community as a whole to work together so that improved and expanded scientific research and the systematic assessment of scientific results, combined with a prediction of impacts, would enable policy options in environment and development to be evaluated on the basis of sound scientific facts'.

All the activities I have referred to here were launched in response to the growing realization of the extent to which human activities on our planet increasingly threaten the Earth's environment, and the growing recognition by governments that scientific knowledge of the earth system is a necessary ingredient for wise policy-making. Changes in the earth system extend across national boundaries and scientific disciplines, thus, the programmes put in place have, by necessity, become international and interdisciplinary. However, systematic investigation on a global scale has only recently become feasible. Given the high cost and the lack of adequate human resources in any national programme to carry out these investigations, the coordination and cohesion of the international research programmes and observations systems are vital, as they will benefit us all. All these mega-science projects have therefore included networking, sharing of facilities, information and ideas. But, the wide interest in the environment has also resulted in some 'turf' battles and duplication of efforts, which are easy to resolve, and should be resolved, as we move towards the 21st century.

I have used the example of environment in international cooperation in science simply because this is what was the most visible during the past 20 years of my own involvement in the world of science. There are many other examples of course. I could have given you a talk about the intensity of cooperative action during this same period in the mathematical sciences, in astronomy or the biological sciences. What characterizes all of these activities is that they involve thousands of scientists throughout the globe driven by the common language of science, a shared curiosity to understand our planet and the belief that science is a truly international endeavour.

Challenges to international cooperation in science and recommendations for action

While all these accomplishments deserve to be recognized and celebrated, there is also some cause for concern that international science has developed resting on its past glories, without taking into consideration the vast and rapid changes that have occurred during the past 50 years. Our world today has become truly a global village and, while science may have been its first international citizen, it now needs to adjust even more rapidly to the reality and pressures of globalization. Given the long experience in thinking beyond their borders, scientists should be able to do this with ease, but a great deal of new action is needed if further progress in scientific cooperation is to be made.

Although science is not an explicitly recognized subject in the new study sponsored by the the United Nations Development Programme (UNDP) on Global Public Goods, many of the recommendations contained in it deserve our attention. A chapter in this study calls knowledge ‘one of the most crucial of public goods’. The challenge, therefore, is to ensure that knowledge is accessible to all, that intellectual property rights do not impede this access and that a knowledge bank is created to assemble, sort, store, disseminate and constantly update knowledge of relevance to all segments of society.

The usual manner of dealing with the world’s problems, by using knowledge or science in a series of quick, patchwork-like fixes, will need to be seriously revised. Thus, while it is widely recognized that knowledge, or international science, holds the key to solving many of the world’s problems, the mechanism to use this key needs some fresh thought. The problems must be addressed in a more interdisciplinary and also global manner and, while this is slowly occurring, more lip service is paid to this notion than should be the case. Scientific programmes should demonstrate real links between the natural, social, medical and engineering sciences as well as relevance to situations ranging from the global to the local. Elements of all this are slowly being put in place, but much more needs to be done.

The separate international research programmes I described earlier, dealing with global change, climate change, biodiversity and the human dimensions, should begin to move towards a merger, which we were not ready for when they were set up. ICSU and UNESCO should take the lead by both truly embracing science in its totality so that the natural, engineering and social sciences are closely linked in all the actions of these august bodies.

In order to prepare ourselves for the 21st century, which many call the ‘century of biology’, much more cohesion in the organization of international cooperation in the biological sciences will be needed. In today’s ICSU, nearly half of the 25 unions are from the biological sciences. Surely such fragmentation cannot be helpful.

International cooperation in science also needs to reach out much more vigorously to those countries where the organization of science is young and those countries which have only recently become convinced of the need to reach beyond their borders. No one has made more contributions to science in the ‘developing’ world than the late Professor Abdus Salam, Nobel Laureate in physics and founder of the Third World Academy of Sciences (TWAS). At the ceremony launching TWAS in 1985, Abdus Salam described international science better than I ever could: ‘Even as we are gathered here in a Third World context, I remain conscious of the fact that science as such has no national affiliation. The history of science, indeed, involves the history of diverse civilizations.’

This is, of course, true and yet, as we gather here in Budapest, the gap between rich and poor countries becomes wider and wider. All the statistics in UNESCO’s excellent *World Science Reports* point to this disparity and to the powerful correlation between wealth and development and investment in science. It is not enough to take note of these stark statistics. Much more needs to be done in and with developing countries so that their scientists are not isolated, so that they are able to remain at home while keeping their full citizenship in the world of international science, so that future generations of scientists are encouraged to flourish and opportunities for training, research and publications are provided and constantly refreshed. This will require significant investments in training and research facilities in the developing world, not necessarily in every country, but perhaps on a regionally shared basis.

As science becomes more universal, it should also be more accessible to women as well as to younger scientists from both genders. An excellent International Forum of Young Scientists was held in Budapest a few days before this Conference and I encourage you to read and consider the recommendations of that forum.

The direct and sometimes indirect contributions by indigenous communities must also be recognized and respected, and international science must find ways to be inclusive of traditional forms of inquiry.

In addition, more international networks of scientists should be created and supported, involving those scientists doing basic research and those interested in applied science and from as many parts of the world as possible. Several of these networks do exist and, while the concept of networks is still fashionable, there are too few donors and examples of success to emulate. Networks are the first steps in creating partnerships, which will be needed more and more if science is to take its just place in the 21st century. While the initial step in the establishment of scientific networks is to link like-minded scientists from various countries, laboratories and institutions together, thereby encouraging them to collaborate and cross-fertilize each other's ideas, wider networks are called for in today's complex world. Scientists will need also to increase their cooperation at the regional level and build bridges to governments, non-governmental organizations (NGOs), business and industry, consumers, the media, younger generations and educators.

International research and training organizations with truly international staff and facilities accessible to scientists from all parts of the world should also be established. The examples of the Abdus Salam International Centre for Theoretical Physics in Trieste, the European Laboratory for Particle Physics (CERN) near Geneva and the Consultative Group on International Agricultural Research (CGIAR) system are excellent, but the list is much too short to meet the challenge of the 21st century. I hardly dare to list here northern universities such as the Massachusetts Institute of Technology (MIT) or the London School of Economics, because they are not international by mandate and yet both institutions attract and encourage students and faculty from all over the world. These institutions have learned that intellectual potential, not national identity or adherence to some ideology, is the key element for advancing knowledge. Why can't the world have more international teaching and research facilities such as these or, even better, institutions that are internationally governed and financed?

What concrete measures will be taken to reduce the isolation of scientists in some parts of the world and therefore to encourage free and open access to scientific knowledge? The President of the US National Academy of Sciences, in a recent address in Washington, expounds the dream of 'connecting all scientists in the world to each other through the Internet', a dream I support fully, but how do we facilitate and channel all this information flow and exchange? More attention also needs to be paid to protecting the integrity and authenticity of the scientific process while encouraging electronic publishing and open access to information.

There is clearly also a fundamental problem with funding that slows down the process of truly internationalizing scientific efforts and of creating strong institutional mechanisms to accomplish this. If science would benefit from being ever more international, as I have tried to make the case, then the funding mechanisms must be created to support this science. In today's world most of the funding comes through national budgets, with a few brave exceptions such as the European Union and some US foundations. What mechanisms can we think of promoting that would provide the funds for international science to flourish and to meet the challenges of tomorrow, without the sort of narrow perspectives national funding agencies are frequently forced to have?

If science is truly international, why is there no obvious international forum where those making high-level decisions about science can sit around the same table? Where do science ministers and heads of national research agencies come together on a regular basis to share policy discussions and decisions? This occurs more and more on the regional level, but should it not also take place internationally? Do the national and the few regional associations for the advancement of science have an effective meeting-place internationally? Could the two sponsors of this Conference add this to their already heavy responsibilities?

Perhaps the answer to all these questions lies in the scientific community's own hesitation in making its case clearly and firmly to policy-makers, to the media and to the general public. Scientists are not known to be the best bridge-builders to other sectors of society, but they, or someone on their behalf, will need to learn better communication skills so that the nature and wonder of science, its promise as well as its risks, are clearly explained not once but on an ongoing basis. Should there not be a renewed effort to provide this interface between science and society and science and policy, so that science can finally be heard as it provides impartial advice on issues key to decisions about the welfare of human beings and this planet, which is our only home?

The role of future leaders

I myself left ICSU nearly two years ago, not because I stopped believing in all that I have told you but simply because I had a chance to contribute specifically in the area of capacity-building in a newer organization, to which I hope I have taken all the valuable lessons I learned at ICSU. My new programme is also an ambitious one, based on many of the elements of international science that I have described here: global capacity-building and partnerships, interdisciplinarity and great energy to bring about change.

The Leadership for Environment and Development (LEAD) programme is a global, independent, education foundation set up by the Rockefeller Foundation in the years just before the Rio conference to provide continuing professional education for outstanding mid-career individuals in both public and private sectors, introducing them to the scientific and policy issues of the environment and development and honing their skills as future leaders who will deal with these problems around the world. LEAD is now an independent foundation with programmes in most parts of the world and I have the challenge of being its first chief executive officer.

LEAD associates are generally drawn from five sectors of society: academia, business, government, media and NGOs. They are between the ages of 30 and 40 and are fully employed in their organizations and are expected to play key roles in their countries, regions or internationally. Their employers contribute to the LEAD programme by allowing the associates to be periodically absent from their jobs during two years while they participate in LEAD training.

Once they complete the training phase of the programme, the associates become LEAD fellows for whom there exists a special programme designed to nurture this growing network of leaders. LEAD ensures that all members of the family (associates and fellows) are kept in close touch with each other and with other, relevant organizations through LEAD's own electronic network, LEADnet.

LEAD presently has just over 1 000 fellows and associates through its member programmes which are found in all parts of the world. Of this network, about 30% are drawn directly from the scientific community. The programme gives them a chance to meet and work with peers from other sectors in their own and in other countries, thereby nurturing an international community of leaders committed to bringing about harmonious change in the way the planet is managed.

Twenty-four LEAD fellows are here at this Conference, having agreed to leave their busy jobs to help contribute to the outcome of our deliberations and to ensure that the follow-up that we will commit ourselves to will take place not only in their home countries but, with the help of the LEAD network, in other parts of the globe as well. I hope that they will bring youthful and fresh perspectives to our deliberations.

Conclusion

I hope that these brief remarks have persuaded you that I am a strong believer in international scientific collaboration, which has made enormous contributions to improving human welfare. We can certainly point to discoveries in many fields of research, such as medicine and agriculture to mention but two, which have made our lives better. I firmly believe that many of these positive developments could not have happened without international cooperation.

At the same time, I also hope to have adequately conveyed my concerns that our ways and organizations of the past 50 years or so will not suffice for the 21st century. The list of future demands is daunting and long. I have tried to touch on a number of these. The institutions fostering international science will need to be further strengthened and be made more responsive to the new challenges. Funding organizations will have to develop better and more global visions and approaches. Scientists will have to give greater attention to improving their ways to communicate with the public, and something needs to be done urgently to increase the scientific capacity of the developing world. Ultimately, new and truly international research institutions will also be needed and securely supported.

Hence I urge this distinguished assembly of representatives from the international scientific community not to rest on its laurels. A conference such as this one is a wonderful occasion to allow us to deservedly applaud our many significant past accomplishments. But even more important than the past is the future and we should concentrate on what challenges and requirements science can and must deal with in the 21st century. While the future by definition is uncertain, we do know that it will pose new issues for us. This Conference provides a unique and not-to-be-missed opportunity to explore these.

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L'enseignement des sciences

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J'envisage de traiter brièvement la façon dont on pourrait enseigner au plus grand nombre le minimum de connaissances scientifiques afin de limiter les dommages engendrés par trop d'ignorance scientifique. C'est donc un objectif limité : je ne chercherai pas à discuter de l'enseignement de l'optique quantique, de la génétique moléculaire ou de la chimie supramoléculaire, mais il me semble nécessaire de chercher à limiter le risque d'illettrisme scientifique total. J'émettrai quand même ensuite quelques idées relatives à des moyens simples de renforcer certains aspects de l'enseignement scientifique de plus haut niveau.

Je commencerai donc par me poser la question des connaissances minimales permettant à un de nos contemporains de mener une vie « normale », une vie « adulte » ne le condamnant pas à être exploité par d'autres, qui, eux, « savent ».

Il y a bien sûr d'abord les « Three Rs » : « Reading, 'Riting and 'Rithmetic ». Ce serait déjà beaucoup dans beaucoup de pays. Mais admettons que les étapes de l'illettrisme total ou partiel aient été franchies – et ensuite ?

Quand j'étais à l'école primaire, nous avions chaque semaine deux ou trois heures de « Leçons de Choses » (« *case studies* »). C'étaient des cours pendant lesquels nous étions évidemment, à l'époque, passifs et sages, et pendant lesquels on nous expliquait le pourquoi et le comment de choses simples faisant partie de notre expérience quotidienne ou pouvant en faire partie. Ces leçons de choses étaient illustrées de dessins schématiques, dont je garde la mémoire photographique. Je revois par exemple le bateau à voile disparaissant à l'horizon mais dont le haut du mât reste visible – ce qui était une des façons de démontrer la rotondité de la Terre. Je revois les dessins en perspective montrant une rivière presque à sec puis en crue, la différence entre un estuaire et un delta, la formation des méandres de la Seine. Je revois le dessin des microbes vus au microscope pour expliquer que nous devions nous laver les mains de temps en temps, et ne pas cracher par terre. Je revois le dessin montrant qu'un kilo de plumes pèse autant qu'un kilo de plomb, mais n'a pas le même volume. Je revois le beau dessin, sur toute une page, d'un paysage dans lequel étaient combinés tous les météores : un arc-en-ciel, un nuage tombant en pluie, un orage avec éclairs, une étoile filante, une météorite, et je crois même une trombe (« tornade »). Je revois la Terre tournant autour du Soleil, avec un hémisphère en grisé – donc dans la nuit – et la Lune tournant autour de la Terre. Et tout de suite après, un joli paysage avec un pommier en fleurs, puis le même en feuilles, puis le même couvert de fruits, et enfin le même nu : les quatre saisons, qu'expliquait le premier schéma...

Dans tous les cas, les explications étaient rudimentaires et s'appliquaient à des faits « premiers », que nous connaissions tous plus ou moins ou que nous étions tout à fait prêts à accepter, comme dans le cas de la voile disparaissant à l'horizon. Il n'y avait donc pas besoin d'expériences faites en classe : il suffisait de regarder les dessins.

Et pourtant, j'ai l'impression que ces Leçons de Choses ont constitué à l'époque précisément ce que nous voudrions, avec aujourd'hui sans doute plus de prétention, que tous les enfants de la Terre puissent apprendre : voir le Monde avec leurs yeux, et que leurs expériences quotidiennes ne soient pas l'occasion de questions sans réponse ou, pire, avec des réponses fondées sur la superstition.

Ma première proposition serait de revoir, modestement, mais en utilisant les moyens modernes d'illustration, comment présenter dans chaque pays le cadre général de vie des enfants de ce pays sur la base de leur expérience quotidienne ou d'images simples. Des photos de la Terre prises de la Lune ou de satellites remplaceraient évidemment avantageusement le voilier s'éloignant. Des photographies simples des saisons locales devraient évidemment remplacer notre pommier et nos quatre saisons européennes : le temps n'est plus des manuels colonialistes apprenant, nous disait-on, aux petits Africains que « Nos ancêtres les Gaulois étaient grands, forts et blonds... ». La mise en garde contre l'alcool pourrait prendre des formes plus strictes que celle qui, de mon temps, nous recommandait de ne jamais boire de vin « que coupé d'eau ». Mais peut-être pourrait-on toujours, ici ou là, reprendre pour montrer que, chauffé, un métal se dilate, la même image du charron cerclant de fer une roue de charrette, ce que je n'ai vu faire qu'une fois, et il y a bien longtemps ; mais ce que j'en ai retenu me sert encore, par exemple, pour ouvrir le couvercle résistant d'un bocal de cornichons.

Cette proposition, d'adapter ce genre d'enseignement aux conditions de chaque pays, devrait être complétée par une autre, tout aussi évidente : il serait nécessaire de l'adapter aux conditions de la vie en ville, devenue pour beaucoup la règle, et qui a complètement changé les conditions d'observations premières : combien d'enfants citadins ont-ils pu voir la Voie Lactée ? Combien savent-ils que les poissons n'existent pas seulement sous forme de parallépipèdes ? Enfin, il aurait été utile de faire un inventaire des notions que l'on peut considérer comme ne devant pas être omises : j'ai parlé de la compréhension de notre cadre de vie géographique et cosmologique, et de la dilatation thermique. Des notions premières comme celles de poids, de force, de température, de temps, de distance, d'aire, de diversité biologique, ou des notions élémentaires mais plus subtiles comme l'existence des gaz, ou même l'existence des molécules, devenues notions premières depuis qu'on les voit, pourraient sans doute y être jointes. Mais mieux vaut un catalogue court et à coup sûr utile qu'une liste trop longue et mal maîtrisable.

A ces Leçons de Choses, on peut et on doit faire une critique évidente. Leur domaine d'application est limité à donner une explication simple à des choses vues ou connues, ou aisément imaginables. Mais elles ne conduisent à aucune nouvelle expérience personnelle, exigeant d'y mettre les mains et d'observer.

Cette remarque avait, déjà de mon temps, conduit à introduire ce qui, fort habilement, avait été appelé des « loisirs dirigés », qui nous ont permis de construire avec nos mains des planeurs en balsa ou de voir avec un microscope rudimentaire les merveilles qui se cachaient dans une mare. En outre, des livres déjà anciens, maintenant centenaires, invitaient à faire des expériences « amusantes ». Je crois bien que c'est en faisant un tourniquet avec un bouchon, une aiguille et deux fourchettes, que j'ai pour la première fois compris l'importance de la position du centre de gravité par rapport au point d'appui – notion utile pour tous, dans bien des circonstances. De nombreux petits journaux pour enfants reprennent ces « expériences amusantes ». Mais beaucoup d'enfants n'ont évidemment jamais l'occasion d'en lire : ce sont des journaux pour enfants riches ou au moins pour enfants de pays riches. Ce pourrait être un objectif utile que de monter un site Internet comprenant de telles expériences pouvant être faites avec les moyens du bord – je veux dire de la rue ou de la campagne.

Je ne crois donc pas que l'ancienneté de méthodes d'enseignement soit en elle-même une raison de les condamner; au contraire, il faudrait adapter les méthodes qui ont fait leurs preuves. Mais des expériences nouvelles sont en train de s'imposer. Je veux parler en particulier de ce qui, en France, s'appelle « La Main à la Pâte ». Il s'agit d'expériences réalisables sans investissement notable en matériel, mais au contraire exigeant une participation intellectuelle de l'enseignant, guidée par des consignes élaborées avec soin par des scientifiques de très haut niveau qui tiennent compte constamment du « retour d'expérience ». Le succès de ces méthodes nouvelles est incontestable, et elles se répandent peu à peu, à un rythme sage. En France, cette expérience a un caractère d'autant plus exemplaire que, contrairement à nos habitudes de pays centralisé, elle n'a pas été élaborée dans le secret des bureaux de l'administration, et que son expansion n'a pas été soudaine, universelle et décrétée par une circulaire ministérielle, mais qu'elle est progressive, et fondée sur le volontariat. Elle n'en est pas moins spectaculaire : actuellement, en France, ce sont 4000 classes qui sont concernées par cette opération, et le mouvement prend de l'ampleur.

Nous ne devons évidemment pas oublier que La Main à la Pâte n'est qu'une adaptation de programmes hands-on similaires mis au point aux États-Unis dans des quartiers difficiles de Chicago et qui doivent tant à Leon Lederman. Il y a aussi une liaison évidente entre les ambitions de ces programmes et les intiatives de l'ICSU, telle le Programme for Capacity Building in Science, avec son bras armé, le Science Corps.

Il peut être enfin intéressant de comparer ces initiatives avec celles qui sont appliquées dans un grand nombre de Musées des Sciences interactifs, comme le British Museum, l'Exploratorium de San Francisco, ou le Palais de la Découverte et la Cité des Sciences et des Techniques à Paris. La différence essentielle est évidemment, du point de vue universel de l'UNESCO, que n'ont accès à ces dernières expériences que ceux qui peuvent rendre visite à ces Musées, dont on peut mal imaginer la multiplication dans les pays pauvres. Même si l'ont peut espérer que, dans ces pays, l'utilisation d'Internet facilitera des contacts directs, ce n'est pas ainsi que pourront être réalisées des expériences hands-on.

Je voudrais quitter le domaine de l'enseignement le plus élémentaire, encore que je sois persuadé que c'est celui qui devrait être l'objet du plus de soins de la part de l'UNESCO, et passer quelques instants sur l'enseignement universitaire spécialisé. Spécialisé ? C'est précisément sur ces mots que je voudrais revenir.

Il est en train de s'introduire sans fanfare, entre les Universités du Monde, des différences énormes sur le plan de la spécialisation.

En France, certains enseignements sont par nature très diversifiés. Par exemple, les études de pharmacie, dont le niveau est traditionnellement très élevé – au moins par comparaison avec d'autres pays développés, comprennent des enseignements de mathématiques, de droit, de chimie, de botanique, de zoologie, de pharmacologie, de biochimie, et j'en passe. Au contraire, il est considéré comme normal qu'un Docteur en mathématiques n'ait suivi aucun enseignement autre que de mathématiques. Avec une pré-spécialisation avant l'entrée en Université, comme au Royaume Uni, la spécialisation peut même être extrême : j'ai connu un collègue chimiste qui n'avait, dans toute sa scolarité secondaire et universitaire, suivi aucun cours d'électricité et seulement un bref cours d'optique, comme toute initiation à la physique.

A l'inverse, je reçois en stage d'été des étudiants en cours d'étude à Harvard, qui combinent des cours de très bon niveau en chimie et en biologie avec des cours d'histoire de l'art ou de pratique de la danse classique. Mon sentiment est qu'ils sont mieux préparés à une vie riche, et même à une vie scientifique productive, que nos étudiants hyperspécialisés.

Enfin, il a été beaucoup question en Europe ces dernières années de cours par alternance, combinant des périodes d'activité universitaire normale avec des périodes d'emploi dans des entreprises. L'objectif est de mieux les préparer à pouvoir choisir entre plusieurs types de carrière à l'issue de leurs études. Je crois en fait que, même pour ceux qui se sentent de toute éternité destinés à faire une carrière dans un domaine précis, une formation rudimentaire à la vie en entreprise, aux exigences d'un travail ayant des conséquences économiques immédiates, à une socialisation plus hétérogène, est une expérience utile. Dans le cadre de mon laboratoire, j'ai ainsi utilisé la bonne volonté d'un réseau de collègues industriels amis, pour permettre à tous mes élèves de thèse ou presque de faire des stages industriels d'été – habituellement dans un pays étranger pour les « européaniser » plus complètement. Quand un thésard soutient son Doctorat en ayant accumulé 11 mois de stages industriels dans cinq pays différents, non seulement il n'a pas grand mal à trouver une situation intéressante dans l'industrie, mais on peut être assuré qu'il ferait aussi un bon enseignant, qu'il sera un meilleur scientifique.

J'avais aussi initialement l'intention de passer en revue quelques-unes des caractéristiques positives et négatives des stages post-doctoraux, qui sont devenus une part si importante de l'enseignement des sciences au niveau le plus élevé et de la création de la communauté universelle des scientifiques. Mais j'ai peur que cela ne dilue mon propos essentiel : il me semble beaucoup plus important de concentrer nos efforts, et pour l'instant nos réflexions, sur l'enseignement des sciences au niveau le plus élémentaire, celui qui doit permettre au plus grand nombre de nos concitoyens, même défavorisés, une meilleure compréhension du Monde où nous vivons.

FORUM I KEYNOTE SPEECH

Reformation of scientific disciplines

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I am honoured to have an opportunity to make a presentation to this important conference. I will talk about some problems about scientific disciplines.

Past evils

Issues concerning the global environment are getting serious. They have already passed the stage of warning and are now entering a stage where action is required. We need to act quickly to sustain the Earth. Governments, corporations and universities have already started making efforts to cope with problems related to the worsening of the global environment, each in their own way.

This, however, is just a beginning. Perhaps deeper thoughtfulness is necessary for humankind to create a really effective approach to sustaining the Earth. This is due to the fact that global environmental problems are newly emerging and humankind has never experienced such problems in the past.

Destruction of the global environment is doubtlessly an evil that attacks and threatens humankind. Historically, we, humankind, have countless experiences of being attacked by evils. Those evils were in many cases huge and powerful, for example pestilences, which killed so many people repeatedly throughout the long history of humankind. For a long time we dealt with diseases in the wrong way, but finally, at the end of the 19th century, the germ, the cause of disease, was identified and methods of preventing infection and of curing disease were found.

Generally, it is said that, although humankind is physically weak, we have conquered the Earth. The reason for this conquest is our physical weakness. In proportion to our weakness, we achieved an intelligence that helped us in our conquest.

In the case of germs, humankind identified them and invented methods to control them. But more importantly, the experiences of fighting against various diseases were collected and systematized into an academic field: bacteriology. Knowledge systematized as an academic field can never be lost through the generations and can be usefully utilized by anyone thereafter. Therefore, academic fields are assets that will never disappear.

Bacteriology is an example of how a domain of useful knowledge was established through an opportunity to fight an evil. It should be stressed that the present example is not a special one. Moreover, we can say that many useful knowledge systems were initiated by humans fighting evils that threatened humankind. It is easily understood that intellectual power is fully brought out and revealed in such dangerous opportunities where we fight for the survival of all human beings.

Actually, we may point to many examples where knowledge was acquired through conquering evils. When knowledge is well systematized, it is called an academic domain.

Civil engineering was derived from floods and droughts. Naval architectural engineering was born of the efforts to fabricate better, safer boats. Structural engineering is a knowledge system that was acquired through another knowledge system that was acquired through various activities for eliminating or mitigating damage to houses, bridges and other structures due to storms or earthquakes.

Not only engineering knowledge – we can give examples in other fields. Greek philosophers created methods of rightful discourse in order, at the risk of their lives, to criticize politicians. The result of systematic knowledge is the theory of logic. Even Newton’s dynamics can be traced back to the astrology by which people wished to avoid bad luck.

Bad luck, despotic politicians, storms, earthquakes, causes of wrecks, floods, droughts and germs: they are all evils for humankind, which hopes to build a safe and comfortable life. Through the long history of humankind, we have successfully eliminated or mitigated the harm done by these evils. Not only have we created the practical means for elimination and mitigation of harm, but we have also integrated the knowledge acquired and established systematic knowledge of various subjects. In other words, technology triggered a domain and grew into science. The highly systematized academic knowledge that is now available can therefore be said to be a glorious asset reflecting the history of human conquest on the Earth.

Modern evils

If we have completed an academic knowledge system that may be applied to cope with and solve any problem confronting us, we should be able to solve the newly emerging problem, the destruction of the environment, by utilizing some of the knowledge systems we have created. It is necessary for us to fully apply the existing knowledge domains and of course we must develop the domain itself using basic research to solve environmental problems relevant to the domain.

However, this alone is not sufficient. The reason why the respective application of knowledge domains cannot be sufficient is because the problem – destruction of the global environment – is an evil that carries intrinsically different characteristics from other evils or older evils. The above-mentioned evils, such as pestilence, were foreign enemies to humankind. These evils existed outside normal humans and sometimes came into the human world and threatened us.

In contrast, the destruction of the global environment is not foreign to us. Phenomenologically, many environmental problems seem to attack humankind from the outside, such as the greenhouse effect or the warming of the Earth, deterioration of water, change of the constituents of air, extinction of useful species, emergence of poisonous substances in soils, etc. If threats exist outside the human world and sometimes attack humankind, we may utilize traditional means to conquer them. When that attack seems similar to one of the evils that we experienced in the past, we may select a relevant existing domain and apply, sometimes develop, the domain to conquer the evil.

If the attack does not seem to belong to any existing domain, then we must initiate a new domain, inventing new practical means and establishing a new knowledge system as a result. We should not be frightened by its newness, because humankind has many experiences from the past where we have encountered new evils and successfully conquered them.

However, the destruction of the global environment is neither a similar evil nor one of the new ones mentioned above. It is not only new but is also of an intrinsically different character. It has already been pointed out that many abnormalities observed in the global environment, such as those mentioned earlier, may be attributed to human activities. And of course, there are many other abnormalities that are obviously attributable to human activities such as atmospheric pollution by exhaust gas, deterioration of soil by waste chemicals and extinction of insects by agricultural chemicals.

The intrinsic character of environmental destruction, whether it is obvious or not, is that the cause is attributed to human activity. More importantly, these human activities have always aimed at creating safer and more comfortable lives for human beings.

Therefore, we are obliged to say that this new evil exists within human good intentions. Regrettably, this character is often observed in the problems of modern society. We may enumerate many examples. Coexistence of rich areas and starving areas on the Earth must be caused by the existence of borders that have been constructed to eliminate the useless struggle between nations but now prevent people from freely moving from starving areas to other abundant areas. An increase in the size of accidents due to the enlargement of automated systems, outbreak of new diseases due to too much application of new medicines, solitude in urban life, ethnic disputes, crimes in cyberspace, educational difficulties for children, etc., are familiar examples. We should not overlook that serious new problems are arising in the medical field. Cloning and gene therapy are mostly expected to be used as curative means, but deep ethical considerations must be examined before proceeding with wider applications, otherwise this will produce an ethical distortion in society. These are all modern evils.

Therefore, we may categorize the evils into two types. One is foreign evils that exist outside of the human world and sometimes attack us. These are past evils. The other is the inner evils that come unintentionally from human activity. They may be called modern evils.

What is necessary?

If the destruction of the global environment has already started, how should we establish principles to cope with the situation and what actions should we take most urgently?

Because the observed phenomena, such as environmental destruction, cover a very wide range and are related to so many knowledge domains, it seems almost impossible to utilize only a few existing knowledge domains, either for eliminating the cause of destruction or for remedying the damage. As mentioned earlier, the phenomena categorized in the destruction of the global environment are: first, changes or deterioration of the natural environment, which have causes that are not easy to identify; and second, deterioration which has causes that are easy to identify but difficult to eliminate because of social and sometimes economic reasons and a low availability of environmentally better alternatives. These two categories require different approaches. When we deal with the first one, we need to utilize observational methods to analyse the causes of the deterioration. Fundamentally, this approach may be similar to basic science. On the other hand, when we deal with the second category, we should utilize not only the methods of basic science but also the methods of engineering, economics, social sciences and policy-making. In addition to the wide range of problems due to the above-mentioned categories, we may easily find another factor that widens the range of domains. Just by looking at examples of the destruction, we must realize that so many knowledge domains are related to the destruction phenomena.

Deterioration of water is related to geology, meteorology, chemistry, agriculture, urban engineering, manufacturing engineering and, of course, water purifying engineering. If we think of waste processing, we need to invite many different specialists from science, engineering, economy, law and the humanities.

It is doubtless necessary for a vast number of academic domains to be involved in research on environmental issues, each of them taking a different approach according to their subject. It should be stressed here that it is necessary to develop new knowledge and methodologies not only in each domain in parallel, but also through collaboration between fields. It is easily seen that phenomena observed in the destruction of the global environment are the results of the complex integration of many different causes. No phenomenon is the result of an activity related to a single knowledge domain. Collaboration of different specialists is essential in analysing the complex phenomena and proposing feasible plans.

What is sufficient?

Here, can we think that the collaborative involvement of researchers from relevant academic fields is enough to create useful results contributing to practical actions to eliminate the cause and remedy the damage?

It is absolutely necessary to collaborate, but this alone is not sufficient for the following reason. We must consider again the intrinsic character of modern evils. They are inner evils. That is, the true causes are invisibly included within our well-intentioned activities.

In the past, engineers were motivated to improve the performance of products in their engineering domain. They strived to be faster in transportation, more reliable in mechanical structure, more rapid in calculation and more accurate in measurement and manufacturing. These are consistent with corporative purposes and appreciated by consumers. Here, we can observe harmony between specialists’ motivations and consumers’ wishes.

If the destruction of the global environment is an inner evil, the cause could exist invisibly in human intentions and therefore this harmony could be destroyed. We should conclude theoretically that it is to be destroyed. Moreover, we are required to see that this destruction actually takes place.

In the past, a car was thought better when the size was larger and the speed was higher because the basic purposes of the car, comfort and usefulness, were both more fully realized. The original function of the car was to move people more quickly with more comfort. Correspondingly, the knowledge system, mechanical engineering, motivates automotive engineers and intrinsically incorporates the value that the faster and the more comfortable a car is, the better.

Generally, as mentioned earlier, many knowledge systems have intrinsic values, whether they are visible or not, depending on their origins. A domain was initiated for fighting a past evil and later grew into systematic knowledge to be utilized for the development of more comfortable tools, devices, conditions and environment in the relevant domain. This very concept of comfort in this domain backs up the value that is intrinsic to the domain.

If an engineer is asked to design a car that minimizes the burden on the environment, he must moderate the intentions intrinsic to his specialty to a considerable extent. In most cases, engineers are required to moderate their original dreams coming from their specialty into ones that are compromises and this generates some frustrations. In actual situations, we often appeal to their morality as citizens asking them to moderate their ambitions as specialists.

Is this the inevitable attitude by which people act in a society where sustainability is the central concern? Unfortunately, we cannot deny this when we consider the history of the development of knowledge. Here is a serious gap between motivations of normal people and specialists, and consequently there will be a rising deterioration of human morale to conquer any evils they encounter.

It is reasonably easy to understand that a technological domain intrinsically carries a value that affects the motivation of specialists, even if it becomes mature enough to be described in purely scientific terms, as is often seen with fundamental subjects of engineering education. On the other hand, many people may believe that any one of the domains of pure science is perfectly free of values. But this is doubtful, in spite of its being common sense.

Let us think of a simple example. Traditionally, the subjects of scientific studies have been divided into domains. Most fundamentally they are divided into two domains as living things and non-living things. Living things are divided further into plants and animals, establishing botany and zoology.

Taxonomy has been one of the most important methods used for the development of science historically and this has resulted in many scientific domains. Sometime in the past, scientific studies used to be conducted independently of other domains. A typical example is the study of matter: studies of plants and animals had been conducted independently and consequently knowledge was separated between botany and zoology. And needless to say, both of them were independent of mineralogy.

This is exactly the reason, unfortunately, why humankind has long been losing sight of the circulation of matter through plants, animals and minerals on the Earth, which is now identified as being one of the most important 'natural' phenomena to be studied scientifically.

More than 2 000 years ago, a Greek philosopher, Democritus, was the first to point out that matter was made of atoms and emptiness, and secondly that atoms would never disappear from natural things. Strangely, modern scientists were only interested in the first point by Democritus and investigated deeply the atom, that is the structure of matter. They have been attacking the secret of matter and have already reached the extremity of the elementary particles level.

On the other hand, they paid little attention to the second point by Democritus, that is the law of indestructibility of matter. This is a thing left behind by modern science. The law implies that matter circulates. However, modern scientists have not yet developed a theory that explains the total system of circulating matter on the Earth, except local circulations within individual domains. Recently, it has suddenly been realized that the global destruction of the environment seems to be attributed to the abnormality of circulation of matter on the Earth. Then, we should conclude that modern science is seriously responsible for the destruction.

We may say that the fundamental cause of the global destruction of the environment is the morphology of scientific knowledge: that is, the over-fragmented structure of scientific domains. Here, we conclude that the necessary condition for resisting the deterioration of the global environment is the cooperation of scientists and engineers from various fields, while the sufficient condition for recovering the environment is thorough reformation of the structure of scientific knowledge.

A proposal

We have elaborated the characteristics of the problem of global destruction of the environment and concluded that it can be attributed to the artefacts developed by the separate efforts of people utilizing particular knowledge from the fragmented scientific domains. Thus, the most fundamental cause is the morphology of knowledge.

The environmental problem is an example of a modern evil and we have already mentioned other examples such as the coexistence of rich and starving areas. The analysis of the problem of destruction of the global environment is also applicable to other modern evils. They are all caused by particular artefacts, either material or institutional, that were created by human efforts in order to solve individual problems by applying the particular knowledge that was useful, at least for solving them primarily. Those artefacts have interacted with others gradually and generated new problems that could never have been expected within the particular domains.

We need to apply useful knowledge in fighting those modern evils. This useful knowledge would be obtained from the corresponding scientific domain. Then how can we establish the scientific domains from which we can develop useful knowledge for the fight? We must select an alternative to the traditional scientific method successfully applied to fight past evils.

Let me propose a method for creating useful knowledge that will confront emerging modern evils, that is, a bird's-eye-view project for scientific research. In this project, researchers will come together from various scientific fields categorized into two groups. The first group works on realizing the main target of the particular project, creating new knowledge, while the second group works on analysing the influences of knowledge on society. The second may not only estimate the scientific result of research itself but also forecast the state of the society to which the result might be applied after the project is finished.

Researchers from both groups, each of which may include respective different domains, are requested to work together and concurrently, not only integrating knowledge from their domains but also cooperatively reforming individual research motivations that are expected to grow wider than those enclosed in their particular scientific domains, including natural sciences, engineering, social sciences and letters. Sometimes, it is necessary to invite policy-makers to the second group. We may say that this reformation of motivations will generate a birds-eye view.

This kind of project will be one of the promising practical devices where researchers can widen the scope of their research activity. Needless to say, the most crucial point is the opening of a researcher's mind to emerging problems that are quite new and different from the past. As scientists or engineers, we must try to open our minds to new problems and also should not hesitate to reform our research motivations through collaboration with researchers in other domains.

What makes science unique in the experience of mankind? The specificity of the scientific approach

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Defining the nature of science is the main task of the philosophy of science. In what follows, the traditional approach of science philosophers will be counterpoised by a more recent approach more suitable for science in the 21st century.

The traditional stream in the philosophy of science, namely the analytic-empiricist (or neo-positivist) tradition followed by authors like Rudolf Carnap, Hans Reichenbach and Carl Gustav Hempel (to mention but a few) holds a strong view of science according to which it is possible to formulate general standards of scientific procedure; to analyse the logical structure of scientific knowledge; and to show that science serves the rational pursuit of acquiring reliable knowledge of the world in which we live. The tool adopted by such authors in order to analyse science is logical analysis based on formal logic developed by Peano, Frege, Russell, Whitehead and others. The idea is that, by making use of logical analysis, one can show that scientific language has a very special character, namely that of being unambiguous. In this connection, analytic-empiricist philosophers put forward the 'verificationist' view according to which the propositions belonging to the empirical sciences are meaningful if they are verifiable by experimental observation. A 'physical theory of truth' provides a verification procedure which consists first in defining an 'observational language' describing experimental data, and secondly in translating the whole language of science (usually including also theoretical terms referring to unobservables) into sentences of an 'observational language' shaped on the language of physics. This position has been called 'reductionism'. Reduction to the empirically given, or at least the possibility of performing such a reduction, plays the double role of a criterion of meaningfulness and a criterion of demarcation between science and pseudo-science. While scientific statements are anchored to experience in the way just specified, statements lacking this property do not have any content and are therefore deemed meaningless. Such are the expressions belonging to metaphysics or to pseudo-sciences like astrology. This is the core of the so-called 'verifiability theory of meaning', which also offers a criterion of demarcation between genuine scientific statements and statements belonging to pseudo-science.

Logical analysis also gives us the means to perform a 'rational reconstruction' of the nature and methods of scientific knowledge. Performing a rational reconstruction amounts to exhibiting the logical structure of science. This may require rearranging scientific knowledge in a consistent scheme, filling conceptual gaps and specifying connections that are not explicitly stated in the reports made by scientists, such as making tacit assumptions explicit or showing the relationship between theoretical and observational statements. Analytic-empiricist thinkers see rational reconstruction as the main task of epistemology and consider the capacity to undergo this process as a distinctive feature of science.

The ideal of rational reconstruction is based on a sharp distinction between a 'context of discovery' and a 'context of justification'. The context of discovery covers the process leading to the formulation of scientific hypotheses, including experimentation. According to analytic-empiricist philosophers, the context of discovery is of the exclusive concern of scientists, whereas philosophers are committed to the context of justification, aiming at the clarification of the logical structure of scientific theories and the inferential methods employed first to obtain then to verify these theories. In this perspective, the analysis of the structure of scientific knowledge is confined to its syntactical aspects.

In addition to analysing the structure of scientific theories, rational reconstruction applies to explanation and prediction, considered the main goals of science. The latter are taken to be 'nomological' conceptual operations, namely activities which require the use of empirical laws (or empirical generalizations), expressing correlations between phenomena of different kinds. The emphasis on the importance of explanation and the insistence on the adoption of laws as essential ingredients of the rational reconstruction of science are typical of analytic-empiricist epistemology. Indeed, this tradition stresses the capacity to formulate laws that enable us to explain facts and to predict future events with accuracy as being another important, distinctive feature of science. Furthermore, laws – as well as explanation and prediction – are obtained by means of inferential procedures that are themselves definable in a clear and unambiguous way. This brings us to induction and deduction, both of which play a crucial role within this view of science. According to neo-positivists, a hypothetico-deductive procedure, resulting from a combination of induction and deduction, is needed in order to obtain the theoretical constructs that make explanation and prediction possible.

To sum up, according to the neo-positivistic picture, science is a rational enterprise because of its explanatory and predictive power. Moreover, science is intersubjective, being endowed with an unambiguous language and a methodological apparatus whose structure can be fully analysed and clarified. By 1929 (when their Manifesto was published) neo-positivists believed that their conception of science, namely science seen through the lenses of logical analysis and modelled upon physics, could serve as the basis on which to build the unity of knowledge. In quite a utopian manner, they patronized a ‘scientific conception of the world’ intended to shape a new way of life, free from prejudice and open to intersubjectivity.

The neo-positivist conception of science was too strong not to have any weaknesses. And objections were not slow in coming. A first objection is that the picture of science devised by neo-positivists does not suit the social sciences, where the use of general laws and theories is more restricted than in physics. Furthermore, Popper rejected both induction and verification, to which he opposed his epistemology of ‘conjectures and refutations’. Together with induction and verifiability, Popper gets rid of the other keystones of analytic-empiricist epistemology, namely the distinction between theoretical and observational terms and that between context of discovery and the context of justification, to which he opposes the conviction that all terms are theoretical to some degree and that observation is always ‘theory-laden’. Popper’s work has opened the door to an alternative stream in the philosophy of science, namely the post-positivist school, including Norwood Russell Hanson, Thomas Kuhn, Imre Lakatos and Paul Feyerabend. These authors call attention to the pragmatic aspects of science. With the work of these authors, the analysis of science flees from the safe shores of logical analysis, sharp distinctions and all-encompassing methodology to embrace relativism. Feyerabend goes farther, advocating methodological anarchism, on the claim that there is no way of giving a univocal account of ‘scientificity’ or ‘scientific rationality’. No room seems to be left for an epistemological analysis of the nature and specificity of science.

While the debate between neo- and post-positivists has been occupying the limelight, other authors – Patrick Suppes, Bas van Fraassen, Brian Skyrms, among many others – have been addressing science in yet a different way, which can be broadly characterized as ‘constructivist’ for its interest in model building and experimentation. As a matter of fact, these authors take diversified positions, but I will refer to what I take to be the common traits of their work. The approach in question gives up the search for a univocal description of science and, instead of looking for a monolithic image of it, adopts a pragmatic attitude according to which both science and epistemology are problem-solving activities directed to particular issues. The task of epistemology becomes that of scrutinizing the theoretical and methodological apparatus of single disciplines taking into account their experimental aspects, which are considered no less important than their theoretical structure.

The interest in experimentation is a crucial aspect of this approach, which does not take empirical data for granted, but makes an attempt to analyse them. The neo-positivist distinction between theoretical and observational language gives way to an image of science as a hierarchy of models, ranging from empirical models, or ‘models of data’ (in Suppes’ terminology), to the mathematical models of theories. We might call this a ‘bottom-up’ approach to stress the fact that it moves from the structure of observation to the structure of theories. This approach is inspired by the conviction that the methodology of observation not only shapes empirical evidence, but can also suggest new theories.

In this perspective, the distinction between the context of discovery and the context of justification is not simply refuted to make room for historical and sociological considerations, it is superseded by an approach that considers discovery and justification as being intertwined. Interest in the context of discovery calls attention to the structures of data, called ‘empirical structures’, which become as important as the formal structures shaping theoretical formulations. Empirical structures are not to be described as syntactical structures; rather, they are determined by statistical methods adopted to collect and organize observational data.

A main feature of this position is a shift from logic to probability. This is stressed by Suppes, who calls his own position ‘probabilistic empiricism’. Probability enters into the analysis of science not only in connection with empirical structures (which are shaped by statistical methodology), but to the extent that it pervades the whole picture of science. The process of acquiring knowledge is modelled upon a Bayesian process of updating opinion in the light of new evidence, with the possibility being entertained that observational evidence is itself uncertain. The statistical methodology of confirmation (based on induction) and of testing hypotheses (shaped on falsification) takes the place of both verification and Popperian falsification.

Science becomes more an activity of constructing models apt to give an adequate (and useful) description of what is experienced than one of discovery of true theories. Models are usually employed for making predictions and, in some cases, they allow for explanation. Here explanation is seen as a pragmatic activity that varies according to what kind of information is required in a certain context. So conceived, explanation ceases to be a privileged goal of science to become one of a number of useful operations that can be performed. The approach at hand is centred on models rather than laws. With respect to laws, models are less general and more flexible; being typically context-dependent, they are loaded with pragmatic elements, such as the specific purpose for which they were built and the kind of data involved. Far from preventing an epistemological analysis of science, the adoption of models in place of laws allows for a comparative analysis of the structure of scientific knowledge in different disciplines. Starting from plurality, this kind of epistemology does not aim at a prearranged unity of science, but rather seeks a transcultural integration among different disciplines.

How modern science was born and developed

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The way modern science was born and developed may be considered from a philosophical point of view. Modern science is generally understood as science as it developed during the last two centuries. Indeed, modern experimentalism (together with its ethical correlates regarding vivisection for instance) took form in the 19th century, a century in which the cognitive content of the human mind also underwent an unprecedented broadening (for instance with the non-Euclidean geometries), which paved the way to the new conceptions of physics at the beginning of the 20th century regarding space and time, matter and energy. Some fundamental scientific questions were posed for the first time in their full clarity in the 19th century, such as the origin of molecular asymmetry or the origin of consciousness in brain mechanisms, both questions which still remain without real answers. Another major development of the 19th century was biological evolution with its far-reaching ideological consequences on the place of man in nature. During this century also, the relationships between science and technology and between science and engineering became more intimate, so that it is quite impossible, at least for sciences like physics and chemistry, to separate scientific growth from the Industrial Revolution. The growth of science was also much dependent on political changes and on new powers, such as Napoleonic France or Bismarckian Germany. For these powers, science was a major tool of economic growth and political leadership, and this has been generally the case since that time, to the point where countries which were not sufficiently convinced of the usefulness of science for society suffered very much.

How was modern science born and how did it develop? One of the causes of scientific development was the rapid change in the social conditions and environment of the work of scientists in the 19th century. Nineteenth-century scientists were citizens endowed with new ideas of scientific and social progress and were for the most part fighting against conservative trends in societies. Nineteenth-century science was ‘made’ not only by established academics endowed with connections with political powers or organized into influential groups like the French chemists of the Société d’Arcueil at the beginning of the century. It was also made by isolated romantic figures working in poor conditions and coming up with unconventional ideas, as would other organic chemists a little later. Nineteenth century science was made also by people who were engineers rather than scientists, like Carnot who worked on the steam engine. The stronger link between science and technology, which is created during the 19th century, is a result of the Industrial Revolution, of the more intensive use of energy sources and forms, heat or electricity for instance. However, what is perhaps most characteristic of 19th-century science is its long-term tendency to organize itself into an autonomous research enterprise in laboratories and institutes with numerous workers. This tendency correlates strongly with the tendency to offer products and serve the needs of society at large, especially of industry and medicine. The organization of chemical research in Germany or of medical research at the Institut Pasteur in France are well-known examples of this process towards autonomy and functionalization, which goes with the growth of science itself.

Nineteenth-century science developed also in a new intellectual environment. Modern experimentalists had a strong sense of innovation. 'Science is revolutionary' said Claude Bernard. This statement means basically that science is essentially and permanently a revolution in itself, a change of ideas, of mental, cognitive structures and also perhaps of organizational structures. In one century – the 19th – during which so many political revolutions took place or were at least attempted, Bernard's judgement of the nature of science is culturally not surprising. It is also rather divinatory for the future, not only of physiology and medicine, but also of physics for instance. The change in every domain of science, the opening up of new fields, the discovery of new phenomena and of new principles underlying various classes of phenomena is a striking feature of 19th-century science which makes it very similar to 20th-century science. From thermodynamics, electromagnetism, biochemistry, organic chemistry, biology itself, to quote just a few new fields, to the principle of energy conservation established by Helmholtz in a general formulation in 1847 or to the second law of thermodynamics, all these developments gave rise to numerous epistemological and philosophical tendencies of great influence, such as positivism which culminated, at the end of the 19th century, in the famous debate on the limits of science in which the Berlin physiologist Emil Du Bois-Reymond was the main figure.

Consequently, the classical philosophical framework of science given by the concept of truth as a correspondence between mind and reality (*adaequatio rei et intellectus*) was taken less and less seriously. The ideas of lawfulness and determinism, which were based on the success of classical Newtonian mechanics and of its mathematical developments, were interpreted by writers like Auguste Comte as a proof of the human mind's ability to describe natural laws pertaining to the phenomenal experience without being able to unravel the internal nature of underlying causalities, forces and substances. In spite of philosophical reactions, mainly in Germany, against Kantian criticism, and in spite of the increasing success of the scientific model given by classical mechanics in astronomy or in more remote domains of physics like electricity, the idea of the limits of science acquired more credit, for instance in pragmatism which developed mostly in Great Britain and the USA and was dominated by such a powerful figure as William James. Surely the idea of an intimate relationship between science and human action (and not only the human mind) had something to do with the increasing ability of scientists to participate in a successful way in the creation of new non-natural things, the case of organic chemistry being paradigmatic in this respect, and thus with the increasing ability of scientists to answer new social and economic demands. However, the philosophical success of positivism and pragmatism at the end of the 19th century (a success which is still continuing today) was based on the view that science had met several unsolvable problems which were enumerated by Emil Du Bois-Reymond in his famous speeches: the problem of the essence of force and matter, the origin of movement, the origin of life, the teleology of nature, the origin of sense perception and the origin of thought and free will.

However, in spite of this attempt to draw boundaries for science, signs of instability of human reason were increasingly clear at the end of the 19th century and these were also signs of possible renewal, particularly in physics. The privileged status of time as an independent variable in the equations of mechanics became increasingly questioned. In the late 19th century, Helmholtz and Mach tried to establish connections between physics, physiology and psychology and to investigate the cognitive foundations of scientific knowledge. The idea of functional dependency between several variables became more obvious in physics and physiology. Physiology became increasingly relevant for physics. These tendencies paved the way, intellectually speaking, for forthcoming revolutions in physics, which were also favoured by new technical devices, new experimental systems and new phenomena at both macro- and micro-levels, like the famous black-body radiation studied by Einstein in 1904. Due to this instability of the basic representations of the human mind, at the end of the 19th century the relationships between man and nature, human reason and nature, became less clear than ever.

As a science born and developed in the 19th century, biology allows us to reach the same conclusion. It is impossible to understand Darwinism without referring to the special relationship between man and nature described in economics, in the work of Malthus for instance. During the course of the 19th century, biology became a science which established itself at the interface between natural science and social science. Social scientists were increasingly interested in biology. Biology's deepest ideological impact did not only pertain to evolutionary mechanisms and natural selection. It also pertained to the new and disturbing place that is given to man within nature, considered most of the time by biologists as the product of chance rather than necessity. In such ideological settings, man's responsibility in the creation of his own future increased tremendously. This is indeed the way things are perceived presently, at a time when biological sciences are ever-more involved in other social debates and economic concerns, and when man's responsibility for the future of biological evolution and the future of the Earth's state is more and more perceived. Moreover, Darwin's explanation of biological evolution by natural selection remained incomplete without a real understanding of variation and inheritance. This was the task of genetics. At the beginning of the 20th century, when Mendel's fundamental work was rediscovered, the ideological dimension of genetics was already being discussed vividly in eugenics, a subject present – sometimes dramatically so – throughout the 20th century. Indeed, ideologies devoid of any real scientific basis flourished and were sometimes put into practice. They corresponded to the most destructive features of human beings. Today the eugenics debate is still continuing, but the lessons from the past have not been forgotten. Eugenics makes no sense genetically, since it diminishes biological diversity, which is a source of evolutionary success. As an ideology seeing the future of humankind in an improvement of its biological features, eugenics is widely condemned for both ethical and scientific reasons.

Modern science, as shaped by the 19th century and expanded in the 20th century, has been the subject of a big widening of the gap between science and basic human reason, a gap which results in educational and other cultural or even ethical difficulties. There is no real proof that a kind of pre-established harmony between the basic cognitive equipment of the human mind and nature exists, in spite of the wonderful powers of mathematical thinking. On these grounds, positivism and pragmatism are still flourishing philosophical tendencies, as they were in the 19th century. These tendencies are in accordance with the fact that science is a learning process, as was already seen by 19th century experimentalists like Claude Bernard. In this process, science enriches and modifies the human mind. To what extent is the human mind able to further realize the old dream of expanding its cognitive powers and thus mastering its relationship with nature? This is a question and a challenge for 21st-century science.

About anti-science, para-science and pseudo-science

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In the 19th century, when the Industrial Revolution was flourishing, groups of workmen destroyed the spinning and weaving machines which they considered a threat to their employment. They were called luddites from the name of their chief Ned Ludd, a poor workman from Lancashire who was, according to historians, mentally challenged. Nevertheless, we have much to learn from them, as we have much to learn from the enemies of Galileo.

While the present Conference was organized by believers for believers, a large part of the population shares attitudes that are not only diffident towards science but in some cases radically hostile. Paradoxically, this is especially true in countries where science and technology have performed their most spectacular growth. It is not just a simple nightmare to imagine that, in the near future, citizens could vote for parties promoting ignorance and cutting off public budgets for scientific research.

The purpose of this paper is thus to draft a typology of the anti-scientific attitudes in a historical epistemological perspective, as well as of the alternative systems of knowledge in which many human beings have invested their hopes. Here we shall have to distinguish between, on the one hand, para-science, from the Greek *para*, 'next to' (i.e. theories and practices which coexist with science without any judgement about their value); and, on the other hand, pseudo-science, from the Greek *pseudomai*, 'to lie' (i.e. fakes and forgeries claiming to be scientific).

About anti-science

In the 1930s, the science historian George Sarton, a famous neo-positivist, wrote in his journal *ISlS*, 'History of science is the history of mankind'. In the optimistic atmosphere of the League of Nations and of the International Council for Intellectual Cooperation, science appeared as the only cumulative and universal process in history. Generating its own values, it was able to become the base of a new humanism. At the same time, the French surrealist poet André Breton exclaimed, 'Throw the physicists into jail, close the laboratories'. A few years later, the Hiroshima bomb revealed that science could also contribute to evil, while Nazi biology, Aryan physics in Germany and the Lysenko affair definitely showed that science can become crazy and perverse.

In the 1960s and 1970s, more and more scientists denounced the collusion between scientific research and the industrial military structure. They became increasingly aware that science was an instrument of domination by one particular social class over the other, by one part of the world over the other. But this criticism did not spread far outside scientists' circles. It only appealed for an ethical and political regulation of scientific practice. It did not call into question science itself. Today the debate takes on a particular shape.

Science itself as a quest for truth is not a subject of contest. A Galileo affair is impossible today, since the great religions of the world have made compromises with scientific advancement. I have indeed met some geocentrists, some creationists, some anti-Darwinians, but they are in some sense living fossils. Far more important in the intellectual world is what is called the post-modern or social constructivist approach. The post-Kuhnian philosophers of science used to consider scientific paradigms as the mere product of a consensus between scientists and they have introduced a relativism which reduces to nothing the specificity of the scientific enterprise as research of the truth in nature. Let us quote here Isabelle Stengers: 'Science is the type of activity which, in given circumstances, is practised by people who call themselves scientists'. This way of thinking should not be underestimated, since it is influential in some political groups.

As far as the average citizen is concerned, science is only considered in its applications, i.e. its immediate achievements, shortcomings and dangers. During several millennia what we call science and what we call technology today lived independently of each other. Since the late 19th century, no significant technological advancement has been possible without a scientific background. That is the reason why, in public opinion, fundamental research and the attitudes towards it are determined by two basic reactions: utilitarianism and fear.

Utilitarianism is expressed in sentences like 'is it wise to invest a huge amount of money in particle physics when half of humanity is suffering from hunger?' or 'there are researchers who spent their whole life carrying out research without discovering anything', or 'there are more people earning a living from cancer than dying from it'. Or even, as a bad guy said, 'it would be useful to inoculate the AIDS virus to some researchers in order to accelerate the process of discovery'. As a matter of fact, people are against science because they expect too much from it.

Hopes and fears with regard to science are reflected in fiction before being clearly expressed. We can connect the Frankenstein of Mary Shelley with the first galvanic experiments and with experimental physiology. Some of today's movies, like *Armageddon* or *Godzilla*, have three types of catastrophes as favourite themes: cybernetical, environmental, biological. These attitudes are deeply rooted in very old ideas recurrent in Western consciousness since antiquity. First, a metaphysical idea of nature, of mother nature, punishing its rebel children and, on the other hand, the nostalgia of the Golden Age of primitive simplicity and the idea of a twofold contrasting progress, as described by the Roman poet Lucretius: the progress of science and technology going hand in hand with decay and a decline of the world and of human behaviour.

About para- and pseudo-science

No wonder then that our contemporaries seek relief in alternative knowledge, that is to say in systems which were excluded from the field of science in its historical development. They seem more human, less dangerous, more efficient, to show more respect towards nature. The positivist approach gathers all these systems under one single label 'pseudo-sciences'. For years, modern science was built in the 16th and 17th centuries on two pillars: *ratio* and *experientia*, calculus and experiment. These tools were first elaborated for physics. Afterwards they were introduced into chemistry, later on into biology, very slowly into the study of the environment and human behaviour. But at the same time, Western science became an instrument of domination and its methodological criteria were considered the only possible evaluation scale for other cultural areas. For the philosophers of the Enlightenment, these systems of knowledge were on the same level as the Greeks and the Latins in the childhood of humankind. That is the reason why traditional systems of knowledge and even folk medicine in the West were never taken seriously. I am especially proud that the President of the International Union of the History and Philosophy of Science, Professor Subbarayappa, is organizing tomorrow with Douglas Nakashima from UNESCO a special session on 'Science and other systems of knowledge'. Traditional ecology, traditional health care, which have been considered so far as extra-scientific or para-scientific, have to find an appropriate place in the new scientific landscape we are sketching here.

But the situation is quite different with regard to astrology, alchemy and the divinatory craft, which were also left aside by modern science. They represent a real danger for the scientific enterprise because their epistemology is totally different. Whereas science is a result of a long series of trial and error, these pseudo-sciences present themselves as revealed by one superior authority or as inherited from more advanced forgotten civilizations. Although they claim to draw arguments from their successes, one should not forget that, in a medieval text, *expertum est* does not mean 'it has been tested' but 'it has been confirmed by an authority'. In this respect, they can even represent a danger for democracy because the owner of the revelation is reputed to belong to a superior order of beings. Finally, their most fruitful argument is drawn from the rhetoric of prosecution. Academic scientists are likened to the Inquisitors of the 16th century.

In the face of this twofold danger of anti-science and pseudo-science, I would like to conclude with a plea for self-criticism among scientists and for the popularization of science. We scientists have the serious duty of being aware of our collusion with imperialism. We have to admit that we built this dual world and dual society. We have to give up our arrogance, share our knowledge and explain that science is not a religion, that science is unable to restore the lost paradise, but that it is nevertheless one of the most fascinating enterprises of humanity.

Western and non-Western science: history and perspectives

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Has a non-Western science ever existed? This seemed to be the first question suggested by the title of this communication. But, as we will see, ethnocentrism has been a limitation for the historical study of world science and for appropriately formulating and answering such a question. At present we know of historical evidence to reply affirmatively to that question. The history of science has been able to substantiate the claim, for example, that in the Chinese, Hindu and Amerindian civilizations original scientific knowledge arose totally independently from the West.

It has also been established that science, as much Western as non-Western, has made a place for transhistorical and transcultural processes of appropriation of scientific knowledge and for diverse forms of scientific activity in different societies. Thanks to that, today we know, for example, that classical Greece was not the unique origin of rational thought and scientific knowledge. The relationship of classical science to cultures of the Near and Far East is expressed by the type of influences that were exercised on it by previous cultures (Egypt, Babylon and China) or contemporary ones (India and China). It is cross-cultural processes that have taken place throughout history and which have ended up constituting one of the main areas or characteristics of science: oecumenism, as Joseph Needham calls it. For the topic of this paper, it is necessary to establish the fact that, in all societies of any time and place, one or several systems of knowledge about natural phenomena such as material and energy processes, the celestial and climatic changes, soil and minerals, plants and animals, human organisms and their illnesses, etc., have been present as one of the central elements of each culture.

The second question is whether non-Western science has been reducible to the Westerner, that is to say, whether both are not but portions of our scientific knowledge. It has been affirmed equally that non-Western science ended up integrated into the Western scientific tradition in large or small measure and at different moments of its evolution. This was the case, for example, in Greek and Hellenistic times with Mesopotamian algebra, arithmetic and mathematical astronomy; in the high Middle Ages with Islamic mathematics, astronomy, physical optics, natural history and medicine; or as a consequence of the discovery of America with botany, zoology and pharmacology, among others. On the other hand, in some other cases like that of Amerindia, China or India, an abortion of non-Western cognitive traditions took place as a result of the imposition of Western science, which did not integrate those traditions into the Western science mainstream because of that abortion. It is true that areas of knowledge that were developed outside the West, although recent arrivals, still have not been integrated into Western science, as in the very well-known cases of Chinese acupuncture, traditional mathematics, or the traditional medicine of several regions.

On the other hand, in terms of modern science, one of the main characteristics is the one regarding geographical expansionism in regions outside Europe and, in certain cases that have been documented in Europe itself, in regions far from main scientific centres. This is another 'transculturation' which is historically recent but is the one that has been the most widespread, to the point of becoming a world phenomenon at the present time. The diffusion of science that took place during the last 500 years led to a 'Westernization' of the societies where it was implanted. However, it did not mean that a resulting homogeneity of the simple adoption of the scientific practice that was typical in Europe took place. In the European case this was because of social, economic and cultural conditions. Nor did it give way to the surrendering of traditional knowledge and traditional culture. What the most recent historiography on the topic presents us with is an interaction of modern science and of its institutions with local cultures, making room for multiple developments of science in other regional civilizations and in other historical processes. This fact led to the formation of new and different scientific practices peculiar to each case, the resulting processes of local domestication to which science was subjected. In general, at present it is accepted that the institutionalization of science in diverse societies has been the result of a complex social process and not the simple transfer of knowledge between centres and peripheries. This is a conclusion that will surely enlighten science policies carried out by governments of numerous non-Western countries and also for international public and private bodies whose actions have been guided by the idea that what is needed to modernize is a kind of a hypodermic injection to get a quick inoculation of foreign science and its institutions in non-modern societies.

Now, let us take a look into the future. In recent years, many futurologists have appeared and their visions of what we should expect in the next century are more or less imaginary and catastrophist. In contrast, a serious and thoughtful book was recently published by UNESCO: *Our Creative Diversity* (1996), containing a report of the World Commission on Culture and Development. The President of that Commission, Javier Pérez de Cuellar, former Secretary-General of the United Nations, observed that ‘the initiatives for development had failed with frequency because in many of the development projects the importance of the human factor was underestimated, the complex fabric of relationship and beliefs, values and motives is the heart of a culture’ (p. 11). This statement makes us rethink the very process of development and has corresponded to the previously mentioned UNESCO Commission which was created for that task. Development – as affirmed in another place in the report – ‘can no longer be conceived as a singular path, uniform and linear, because that would eliminate the inevitable diversity and cultural experimentation and would gravely limit the creative capacity of humanity with its valuable path and unpredictable future.’ This affirmation by the Commission, in itself, converts the subject of cultural diversity into a true means of achieving the strategies required for construction of greater opportunities in the future for all humanity. In the face of the change in focus that such a declaration suggests, a change in perspective should also take place and as a consequence we should stop assigning a ‘purely instrumental role to culture in order to attribute it, instead, a constructive, constitutive and creative role’. This implies beginning the conception of development in a different way, particularly by abandoning some of the most influential economic and political theories at the end of the 20th century, which as far as science and technology are concerned consider them only as merchandise to be bought and sold.

A contemporary history of science offers us a renewed vision of what has been the scientific experience of humanity. Beginning with an interpretation that has a solid conceptual and factual basis and is already far from Eurocentric ideas and a linear development of science, an existing cultural diversity in scientific material is brought into evidence. It is from this point of view that conceivable perspectives and alternatives result for the development of science, as much Western as non-Western. I hope that it will become evident to everyone that, although the initial step has been taken by the historiography of science, the restoration of cultural diversity as an essential part of scientific practice and its development has not yet taken place.

As is happening in other fields, at this turn of the century we are witnessing a review of our ideas about the nature of science. We are doing that by means of incorporating social and historical processes that we know have acted on their evolution. From a more or less static vision of science in place for too long, we are moving towards another vision of a dynamic nature. That is one step forward which will have great importance, since it is a call to modify our current conceptions and attitudes in subjects such as general education and the teaching of the sciences in particular; the scientific policy of the state and private enterprise; public communication of science; the relationship of science to society, culture and history; the self-value of societies; and programmes for cultural, economic and social development.

In consequence, it seems that two tasks are a priority in the immediate future. The first is to develop, preferably within an international framework like UNESCO, advanced investigations into the history of national science in all countries, as well as international science that has been developed in the 20th century, so that such histories are capable of giving us the diversified image needed. This may contribute to the writing of a true world history of science.

The second is to fuel our national and international projects for development with the valuable empirical information that historical and social studies of local science provide us with, so as to give ourselves the realism that has normally been lacking at the point of creating prospects for the future that we aspire to and in the definition of that future. It is also true that, in order to transform the present situation, we must learn about local science and learn about it in its evolutionary and interactive movement.

The invention of classical scientific modernity

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From an epistemological point of view, classical scientific modernity can be fully characterized by two terms: algebraic and experimental. From a historical point of view, science has become more and more 'international', as much on account of its sources as through its development and extensions.

These main characteristics were founded between the 9th and 13th centuries by scholars scattered between Muslim Spain and the outposts of China, but who were all writing in Arabic. The appropriation of this new rationality by scholars began in the 16th century, which gave rise to improvements.

It would then seem essential that whoever wishes to understand classical modernity should break with the periodization drawn by historians, founded on a causal link between the events of political, religious and literary Renaissance history and events in science. This new historical knowledge is required to better understand the historical universality of science.

A new survey of the Needham Question

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What is the 'Needham Question' and the core of this talk?

'Why did modern science, the mathematization of hypotheses about Nature, with all its implications for advanced technology, take its meteoric rise only in the West at the time of Galileo?' (Needham, 1969).

This question was repeatedly raised by Dr Joseph Needham (1900-1995) in his multi-volume *Science and Civilization in China* (hereafter SCC). In fact, a great deal of Needham's writing on the scientific tradition and achievements in ancient China relates to this question or its equivalents. Numerous answers and arguments, including several from Needham himself, were proposed in the past half a century. Nowadays the 'Needham Question', as historians call it, is still a topical subject among the historians of science in the world, and its intention goes far beyond science and China.

In the People's Republic of China, this topic has been paid great attention, especially since the 1980s. The most interesting article, reporting in detail the development of this topic in China, is Fang Dainian's *The Discussions on the Reasons of Backwardness of Chinese Modern Science* (1997).

However, this talk will not discuss the various dynamic factors, no matter whether they are internal or external to science. Instead, it will propose a brief introduction to new research concerning this topic and a special emphasis will be given to the origin and development of this question, as well as its significance in the historiography of world science.

The Origin of the Needham Question

'What factors had stunted the growth of Chinese science?' Dominicus Barrenin (1665-1741), a French Jesuit who came to China in 1698, was the man who first seriously raised the Chinese science 'backwardness' issue in the world. In a letter to Dortous de Mairan (1678-1771), the President and later Permanent Secretary of the French Academy of Science, Barrenin wrote: 'There are many causes entangled together, which have prevented science from developing in expected progress, and as long as these causes still exist, any move forward is blocked' (Han, 1992).

G.W. Leibniz (1646-1716) had a different judgement and analysis of the 'backwardness' issue. In *Novissima Sinica*, he argued that the basic reason for this issue was that the Chinese do not lay stress on mathematics. On the other hand, D. Hume (1711-1776) adopted the sociological point of view and he believed several neighbouring and independent states connected by trade and intercourse would be more beneficial for the advancement of cultivation and learning, whereas China was severely short of this.

At the beginning of the 20th century, the 'backwardness' issue also became a heated topic among Chinese scholars. In 1915, Ren Hongjun (1886-1961), one of the forerunners of Chinese modern science, published an article 'On the Reasons why China does not have Science', in vol. 1 of *Science*, in which he claimed that the main reason was that the Chinese did not employ the method of induction. Later, in 1920, Liang Qichao, in his *Introduction to Learning in the Qing*

Dynasty, claimed that the method of philology in the Qing Dynasty was quite 'scientific' and the underdevelopment of natural science should be mainly imputed to traditional ethics which placed less stress on science. In 1944, when the Chinese Society of Science celebrated its 30th anniversary, a translation of the paper 'Why Natural Science did not Rise in China' was published in *Science Times*, written by a German Marxist historian, A. Wittfogel, who was assumed to have an impact on Joseph Needham. As a member of the Chinese Society of Science, Needham participated in the annual meeting and gave his address on 'Chinese Science and Civilization' in which he first criticized the argument that there was no science in ancient China; he then said ancient Chinese philosophy was very close to scientific explanation and that those inventions and creations of later ages had had a tremendous influence on the culture of the entire world. Therefore, the fundamental problem was why modern experimental science and the theoretical system were produced only in the West rather than in China? Here, Needham had in fact proposed very clearly the Needham Question.

All these arguments emerged before the SCC became widely popular among academic circles.

The global significance of the Needham Question

The ultimate goal of Needham's SCC was to promote mutual understanding among different cultures. According to the new humanism that we recognize in George Sarton (1884-1956) and Needham himself, science, like art and literature, is the common heritage of the whole of humankind. In other words, the unity of nature was reflected in the unity of sciences and the latter was an affirmation of the unity of mankind. As Needham wrote in 1966:

'The standpoint here adopted assumes that in the investigation of natural phenomena all men are potentially equal, that the oecumenism of modern science embodies a universal language that they can all comprehensibly speak, that the ancient and medieval sciences – though bearing an obvious ethnic stamp – were concerned with the same natural world and could therefore be subsumed into the same oecumenical natural philosophy, and that this has grown, and will continue to grow among men, *pari passu* with the vast growth of organization and integration in human society, until the coming of the world cooperative commonwealth which will include all peoples as the waters cover the sea.' Therefore, any non-Western culture is no longer to be treated as 'backward' and modern science should be considered as the great composition of scientific knowledge in different civilizations.

Needham's works are not only stressed by contemporary scholars in China; his question also causes global interest. In September 1996, a conference was conceived as a homage to Joseph Needham and took place in New Delhi, India. As the organizers pointed out, 'Science – the Refreshing River', the theme of the conference, was 'inspired by and reflected Needham's lifelong engagement with crossing disciplinary and institutional boundaries, and drew on the constituencies of academic and professional colleagues with varied intellectual and political concerns' (Habib and Raina, 1999).

At the 20th International Congress on History of Science, held in July 1997 in Liège, Belgium, a symposium with the title 'Global History of Science' was dedicated to Joseph Needham. 'We chose to focus on some aspects of the history of 'non-Western science', Catherine Jami, the organizer wrote, 'on which an impressive amount of literature has appeared since the first volume of SCC was published. Besides bringing to light a 'dark continent', this literature raises fundamental methodological and historiographical issues that could and should inform the work of the majority of historians of science, who study the 'West'. We thus intended to enlarge upon Needham's contribution to the construction of a new history of science, which strives to take into account its multifaceted development in all civilizations' (Jami, 1997).

Recently a number of articles more or less dealing with the Needham Question have discussed the social context of different cultures (Jeon, 1995; Park, 1995; Tsukahara *et al.*, 1997; Fuller, 1999; Raina and Habib, 1999).

Science, modernization and Westernization

The triumph of modern science initiated in 17th-century Europe has caused a widely disseminated mythology: science is a heritage only from Western civilization, the civilization originated from Greek and Renaissance Europe; hence the 'modernization' is simply equal to the 'science', and even, ridiculously, to the 'Westernization'.

The problem is: Did Chinese or other non-Western nations experience something that we could call 'modernization' when what is normally considered modern science was unknown to them? 'Modernization-less science' was how Pierre-Etienne Will introduced this broader concept of modernity, based on his analysis of some examples in China and Japan before Westernization; he concluded: 'If there was not much real 'science' in pre-1850 East Asia, at least not in our sense, there occasionally were interesting moves in that direction; an amount fairly variable in nature and according to country or region, to be sure, but sometimes an impressive amount' (Willi, 1995).

In past decades, 'modernity' and 'modern science' have been frequently attacked by various groups of criticizers: from post-modernists to feminists, from ecologists to humanists, etc. For example, they criticize humankind for using modern science only to conquer nature, but not to care for it, which has led to natural resources becoming exhausted and to a damaged ecological environment.

Nevertheless, science has not gone to its end. For a developing country, people should not only explore the reasons behind 'backwardness'; more importantly, they may also need to find a way of maintaining the coexistence of modern science and traditional science, and promote their prosperity together, as people do with traditional Chinese medicine and modern Western medicine.

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Thematic meeting report

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Participants in this thematic meeting raised various aspects of the question: what is the nature of science? An overview of the major 20th century philosophical suggestions about the nature of science and how they have significantly changed in the last 50 years was presented and developed. Generally speaking, the transition was characterized as a move away from the logical analysis of the structure of scientific knowledge, as well as a move away from analysis of the universal standards of scientific procedures (the 'scientific method'). These traditional views had led to a sharp split between the natural sciences and the social sciences. More recently, philosophical suggestions on the nature of science have moved towards an emphasis on the pragmatic aspects of scientific knowledge as a problem-solving, case-based activity. Contemporary work in the philosophy of science is shifting towards placing more emphasis on the use of pragmatic, local, but hierarchical models in science, and understanding the role of experimentation, rather than the discovery of true laws of nature. This has led to a substantially more pluralistic view of science and, consequently, allowed the natural sciences, such as physics, to be brought closer to the social and human sciences.

A second attempt to shed some light on the nature of science begins with the historical question: how was science born and developed? It was argued that, to answer these questions, the scientific revolution through which modern science was formed in the 19th century cannot be understood outside the context of the Industrial Revolution and political developments. Such economic, political and social developments deeply influenced contemporary science, which was presented as a learning process that enriches and modifies the human mind.

It was suggested that anti-scientific viewpoints have been around at least since the 19th century and many of the lessons about contemporary dissatisfaction with science can be learned by examining them. The most important source of widespread discontent with science is that the perspective of the average citizen is shaped primarily by the results of its technological applications. This leads to a curious mixture of utilitarianism and anxiety which promotes the uncritical acceptance of so-called alternative knowledge systems. There are many sources of the rejection of science, which range from its perceived insensitivity to human needs, its role in environmental degradation, its responsibility for moral decay, to the desire to return to a more natural age. For many, Western science has come to be seen as a means of cultural domination. It was suggested that science can and should combat these anti-science trends by incorporating traditional knowledge systems. Emphasis was placed on the threat to science that anti-science can pose. It was suggested that anti-science is not based on experiment but on authority, and as such it also represents a threat to democracy.

In discussions, a recurring topic was the attempt to diagnose the cause of widespread disillusionment with contemporary science. It was suggested that a main source of this attitude was the perceived arrogance of the scientific world-view and that science needs to be more modest if it is to win more general support. Suggestions included emphasizing science's ability to provide new spiritual power by shifting attention away from physics towards cognitive science, as well as the need for a new world-view, or change in paradigm, in light of quantum theory, chaos theory and complexity theory, all of which should move us away from the idea that physics unveils reality. A critical remark pointed to the lack of emphasis, in discussions on the nature of science, on the role of the intellect in creating the appearance of objective reality.

The standard Western view that classical Greece was the origin of rationality was challenged. It was argued that the development of rationality was a cross-cultural process and that unbiased histories of the actual developments of the sciences needed to be undertaken. It should be recognized that each culture studies nature in its own way and that the complex interaction of science with local cultures is not simply a matter of knowledge transfer. Contemporary historiography of science should give up the idea that there is a Western monopoly on the development of science. Several strategies for understanding the globalization of science were evaluated. Conclusions included the need to recognize cultural diversity as an essential part of scientific practice and the role that a more accurate, less biased history of science should contribute to the modification of current attitudes through education and communication, in order to fuel national and international development.

The issue of the internationalization of science was discussed. It was argued that we need to get the historical facts straight in order to understand the extent to which the epistemology of science can be said to be universal. An historical account of the evolution of science based on the development of mathematics and the many kinds of uses of experiment was given. It traced the origin of the so-called scientific revolution back to the development of mathematical rationality in the 9th century in Baghdad, a period during which science became international by bringing together many diverse traditions. The movement was extended in the 10th, 11th and 12th centuries when Arabic was the language of science.

The final topic developed and discussed concerned the significance of the Needham Question: Why did modern science, the mathematization of hypotheses about nature, with all of its implications for advanced technology, pursue its meteoric rise only in the West at the time of Galileo? The significance of the question was deemed to lie in its role in pioneering the integration of non-Western traditions and achievements into the history of science, in order to promote a more accurate global account of the history of science.

During discussion, it was pointed out that the distinction between Eastern and Western science as characterized by the holistic as opposed to the analytic approach, should be considered prescriptive, not descriptive. The important questions are, can we harmonize the two and to what extent should we try? The idea that some form of science has always existed in every culture was emphasized. Disappointment was expressed at the lack of any paper arguing for improving the university curriculum by being more open about the destructive aspects of colonial science. The distinction between Western and non-Western science was criticized as being too narrow. The issue of a need for a role for spirituality in science as a science of self-recreation was voiced. It was also suggested that some lessons could be learned about the nature of scientific advances by looking at the factors inhibiting progress in scientific research in contemporary Chinese society as it has been politically, socially and historically shaped.

Science as a productive force

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In this short exposition, we shall discuss the need for science as a fundamentally productive force in society and the requirements for enabling science to play this fundamental role.

Historically, science was invented for productive-cum-cultural purposes. Little scientific knowledge was required for organizational and navigational purposes in primitive agricultural societies. In such societies, science occupied a merely peripheral position in productive and cultural systems because most productive activities depended on intuitive experimental knowledge. It was theology and not science that remained central to their preoccupations. Accordingly, science was allowed to be and to develop to the limitations of the extent that it accorded with theology. That explains the methodologies for the production of knowledge prevalent in pre-modern societies, crucially at odds with scientific methodology as we know it today.

With the onset of the modern era, the transition from the old, basically theological methodologies to modern scientific methodology constituted a veritable cultural revolution which has had enormous repercussions ever since. It has irreversibly shaken man's conception of himself and the universe at every level of societal life. This revolutionary transition resulted in science drifting from the periphery of culture and production to their centre, replacing theology and intuitive experiential knowledge.

In today's industrial societies, science occupies a central place in more than one sense. Culturally, the scientific approach to thinking and decision-making has unambiguously displaced the theological way. Science has become the major industry of modern times, involving huge budgets and large numbers of employees. It is now a major productive force, in that the means of production and distribution (technology) have increasingly become an embodiment of scientific knowledge. However, the crucial point in this regard is that science has become a major generator of needs and the means to satisfy them. It is a well-known fact that modern society depends on its ability to continually revolutionize its technical powers and means of production, distribution and entertainment. Such ability is inconceivable without science.

Science, as an autonomous enterprise, has become a fundamental condition of modern survival. That explains the major industrial nations' readiness to spend trillions of dollars on seemingly remote and highly abstract sciences such as cosmology, particle physics and mathematics. In this context, we should bear in mind that science is an open totality and a complex organism. It cannot be treated on a fragmentary basis. In pre-modern society, productive needs for this or that fragment of knowledge arose haphazardly; accordingly science qua science was fragmentary and needed theology to unify it. This is no longer the case. In contemporary society, science assumes its proper form as a complex self-unified organism because it is needed as an autonomous enterprise in its complex entirety.

The World Conference on Science should be considered as an opportunity for all nations of the world to reconsider their priorities, at the national, regional and international levels, in readiness for entry into the 21st century. Its convening is a manifestation of the international community's recognition of the significance of the universal role of science in dealing with world crises and providing for an enhanced quality of life for mankind. Such a meeting of stakeholders, national governments and institutions, educational and research establishments, members of the scientific and industrial communities, intergovernmental and non-governmental organizations (IGOs and NGOs) represents the entire spectrum of those with a role to play in the exploitation of science in the service of mankind. The presence of the relevant financial institutions, whether governmental or NGO, reflects their commitment to the scientific enterprise in the light of its positive impact on the quality of human life.

Science has been the key to dramatic transformations in every imaginable field of human endeavour throughout the course of this century, more intensively in the second half. It has provided mankind with both the theoretical and practical approaches to its future. In our rapidly shrinking world, it remains the key to enhancing human life in the next century. We look to science to allay many global threats, e.g. climatic change, environmental degradation. The mismanagement of global resources, their uneven distribution, unsustainable consumer and production patterns – all are alarmingly critical issues. One of our foremost tools in dealing with them is science.

Since the promotion of fundamental research leads to the development of endogenous capacity, governments should also bear the multiple roles of scientific research in mind. Though private sector research (productive sector research and development, R&D) is an inherent factor of progress, it usually takes the form of applied research for short-term results of direct commercial benefit, whereas public research is undertaken under the umbrella of national priorities. In addition, public sector financing of fundamental research expands the frontiers of science, often resulting in long-term beneficial applications. History is full of cases in which the pursuit of pure science led to the unlocking of entire fields of practical applications that had previously been undreamed of. In awareness of this truth, governments must sometimes look beyond short-term results to the unforetold universal value of fundamental science.

Fundamental research in matters of global interest can be strengthened by international support for research in fields such as arid zone development and water resource management. Regional and international cooperation programmes increase the scientific capacity of small countries and a supportive research environment is vital for increased funding. The economic facts are self-evident. The process is one of global give-and-take; access to information is essential to equitable global advances, but it also requires the safeguarding of intellectual property rights within the shared interests of developed and developing countries.

Scientific and technological capacity has proved itself to be a strong foundation for economic, social, cultural and environmentally sound progress. Investing in such capacity is an investment in our common future. Therefore national and institutional strategies should build on the role of science through the consensual conception and application of far-sighted national science and technology (S&T) policies. Parliaments and government must provide a legal, institutional and financial basis for enhanced S&T capacity including incentives for investment, research and innovation. Science should be part of the educational process parallel to the principles of human rights, coexistence, cultural diversity and tolerance from a very early age. Strong scientific research programmes should be implemented at higher-education and postgraduate levels. S&T should be further strengthened with specific emphasis on education and training for application in key sectors. In this regard national policies must also encourage private-sector support for scientific research and strong university-industry linkages, matching supply to demand. Such linkages between the scientific and productive systems maximize the economic benefits of S&T that translate into national wealth. S&T can provide nations with an escape from poverty and dependence.

Scientific progress requires a high level of cooperation at many levels, both intergovernmental and interdisciplinary. An interdisciplinary approach is crucial to the effectiveness of science's role in our future. It can offer us an exact awareness of the many science-social interfaces and their requirements that can be brought to bear on decisions impacting the commitment of political will, time and money to science in accordance with a precise evaluation of social needs.

Scientific ability to approach problem-solving from different perspectives presents society with the solutions to global problems and basic sources of conflict such as inequities in social rights and resource distribution. Scientific investments can therefore prove to be an effective tool for conflict resolution, offering alternative approaches to the unresolved root causes of some of the tensions of the final decade of the 20th century.

New conflicts are contributed to by growing global inequities. Social benefits are ever more unequally distributed both within and among countries. The industrial countries are obviously more capable of responding to their populations' needs. It follows that the varying extent to which countries can adapt to rapid and continually evolving advances in S&T will inevitably define future inequities. The recognition of this trend is of the utmost urgency in developing countries where scientific capacity-building can determine the quality of the future. There can be no total reliance on the relatively meagre resources available through regional and international support. Each developing country has to have the endogenous capacity to grow and to compete globally, whether for international or multilateral funding, or for other economic benefits such as trade relations. Science marks the present and future status of nations.

To achieve our full potential in scientific endeavour meeting the needs of humanity, we must ensure that the applications of the knowledge derived from scientific research safeguard human dignity and the needs of future generations. Scientists must commit themselves to a universal code of ethics in keeping with their social and global responsibility to advance the objectives of human welfare within the aforementioned social contract. They must be governed by a moral sense that takes the consequences of pushing the boundaries of knowledge into consideration. That is another facet of universal value of fundamental science. It is not that man should resist the need to test the limits of knowledge that is at the core of scientific endeavour, but that he should govern his intentions with the human values that protect the well-being of mankind.

The ethics of science have therefore gained increasing significance. The implications are very obvious even to the layman. New grounds must be established for the use of the power humanity has at its disposal. Current research in genetic engineering, for example, resulted in the international community's concern over grave issues that affected human dignity. This led to commendably prompt action by UNESCO, resulting in the unanimous adoption of the Universal *Declaration of the Human Genome and Human Rights*. UNESCO's International Bioethics Committee has been charged with the follow-up to and implementation of the *Declaration*. This illustrates that the ideal relationship between those who generate and apply scientific knowledge, those who fund it and finally those concerned with its impact can only be based on universal values. Otherwise, given the terrifying capacity of new forms of biological and chemical warfare and the scarcity of strategic resources (as a further example), we are all on a very short fuse.

Paradoxically, it is the advancement of science that has also resulted in some of our major problems, namely the arms race. If we could reach a global consensus on the inanity of devoting such massive resources to the capacity for destruction, military production and research capacity-building should, in principle, be at least partially converted to peaceful uses. There have already been many practical and beneficial applications that resulted as a spin-off from military as well as space technology; there could be so many more. It is, however, unfortunate that there has been a steep increase in the percentage of expenditure on military R&D in industrialized countries, to the detriment of peacetime fundamental research. This comes at a time when research programmes aimed at the resolution of global issues are becoming increasingly cost intensive.

Global responsibility for environmental problems that impact the future of our planet is also becoming ever-more evident. Increased urbanization and certain levels of industrial and agricultural activity are causing changes in the biological, chemical and geophysical cycles that governed the world as we first knew it. We face previously unforeseen changes in the forms of air and water pollution, new epidemics, ozone depletion, drought and ecological disasters. The overall need for sustainable and integrated science policies and preventive action is imperative to the survival of this ever-increasingly interdependent and fragile world and its life-support systems.

It is only fitting that the United Nations has proclaimed the year 2000 the International Year for the Culture of Peace. The global scientific community that we represent can play an essentially constructive and beneficial role in the Culture of Peace with a lasting commitment to harnessing science to serve a more equitably balanced and sustainable world. There can be no lasting world peace if basic human needs are not met across the globe. It is imperative that all the Earth's nations commit themselves to humanist ethics in their use of science as part of a social contract. As there is no Utopia on Earth, the very future of humanity depends on the wise application of knowledge, much as it did, allegorically speaking, before we were turned out of the Garden of Eden.

In closing, it is worth noting that in the 20th century the strongest initiatives towards safeguarding the welfare of mankind usually came about at the end of great and destructive conflicts. We are now at a juncture of history at which the world cannot afford another global conflict. Science has advanced to such an extent that any major conflict could erase life as we know it. International consensus on a framework for scientific action, according to universal values, can provide us with the alternative and peaceful strategies to confront the challenges that threaten us and future generations.

In this sense, science holds the greatest promise for the well-being of humanity, provided modern man succeeds in using science to humanize himself and his natural environment, rather than exploiting it to dehumanize himself and destroy nature.

Forging an alliance between formal and folk ecological knowledge

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This presentation attempts to explore the context and ways of addressing the challenge of forging an alliance of formal and folk ecological knowledge, along with an example of a concrete attempt to develop methodologies for doing so.

Human interactions with natural living resources may be viewed along three dimensions; those of practices, knowledge and belief. Consider as an example, the interaction with trees of genus *Ficus* (Table 1).

Folk knowledge is primarily practical, experiential, localized knowledge. Folk systems do not involve a clear-cut distinction between knowledge and belief (e.g. folk may state that they know that nature spirits live in *Ficus* trees); nor do they insist that knowledge must ultimately be validated with reference to the empirical world. But folk systems do involve substantial information on entities and processes in the empirical world: they include models of the working of the

Table 1. **Human interactions with trees of the genus *Ficus***

	PRACTICE	KNOWLEDGE	BELIEF
Folk	Strict protection and worship of *Ficus* trees	Qualitative understanding of significance of *Ficus* fruit as food for birds, bats, squirrels, monkeys	*Ficus* trees are abodes of nature spirits
Scientific	Partial protection of *Ficus* trees	Quantitative understanding leading to concept of keystone resources	Desirability of conservation of totality of biodiversity

world. In contrast, scientific systems insist on a separation between knowledge and belief; insist that models of the working of the world in the domain of knowledge lead to predictions that can be verified with reference to the empirical world, through deliberately designed experiments. Formal science has achieved many remarkable successes. In particular, simple systems have yielded much understanding through such an approach, for they may be described with the help of a small number of parameters, permitting design of replicated experiments to test predictions.

However, complex systems characteristically require a very large number of parameters for their specifications; every manifestation of the system therefore tends to be unique, rendering replication and experimentation very difficult. As a result, formal science has made very limited advances over folk knowledge in the understanding of behaviour of natural living systems. Most notable of these advances is our understanding of evolution through natural selection. This is a powerful principle, but it only helps appreciate the world after the fact; it has few predictive capabilities; it cannot, for instance, tell us why a primate, rather than a carnivore or a dinosaur, developed symbolic language and capabilities of reasoning.

In particular, we have no ecological generalizations of value in predicting space- and time-dependent behaviour of natural living systems. Hence, systems of management of natural living resources have barely progressed beyond folk systems based on rules of thumb.

As examples, consider systems of conservation of living resources. Among both folk and modern systems of conservation are those (a) based on maintenance of refugia, or localities where biological communities are provided a high level of protection, and (b) special levels of protection provided to specific life history stages. Thus folk systems of conservation include sacred groves and ponds; modern systems include wildlife sanctuaries and national parks. Folk as well as modern systems include protection to life history stages such as birds breeding in a heronary. The science of ecology provides theoretical justification for such practices, but goes little beyond that. The simple rules of thumb derived from folk-level knowledge are thus in a way on a par with modern scientific understanding as far as underpinning conservation practices is concerned. Obviously, the field of management of natural living resources is a particularly appropriate field for an inter-cultural dialogue between folk and scientific knowledge systems.

A major scientific attempt to progress beyond this stage of folk knowledge is the notion of maximum sustainable yield (MSY). Its operation in comparison with folk systems may be summarized as in Table 2 and Figure 1.

Table 2. **'Maximum sustainable yield' – folk systems vs scientific approach**

	PRACTICE	KNOWLEDGE	BELIEF
Folk	Reduce harvests if resource population has become very low	Populations at low levels may decline drastically under continued harvests	Humans part of a community of beings; should respect nature
Scientific	Exploitation at maximum sustainable yield levels	Quantitative models of dynamics of harvested populations	Humans hold dominion over nature; may exploit it to further human aspirations

However, exploitation under such MSY regimes has in very many cases led to over-harvest and resource collapse. This failure of science to generate adequate prescriptions for sustainable use derives from the weakness of the scientific knowledge base, e.g. models of dynamics of harvested populations have not been adequately validated empirically. For instance, many of these assume a parabolic relationship between stock or population at a given time and recruitment. If one actually plots the empirical data, however, there is little basis for the validity of such a postulate (Figure 1).

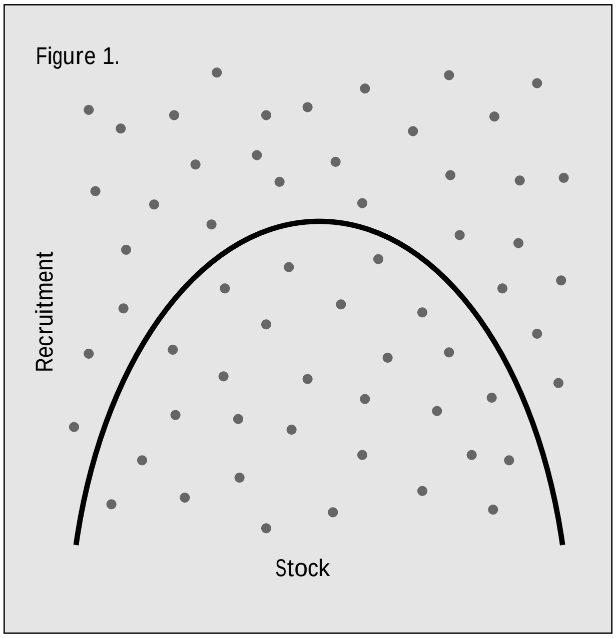
Figure 1.

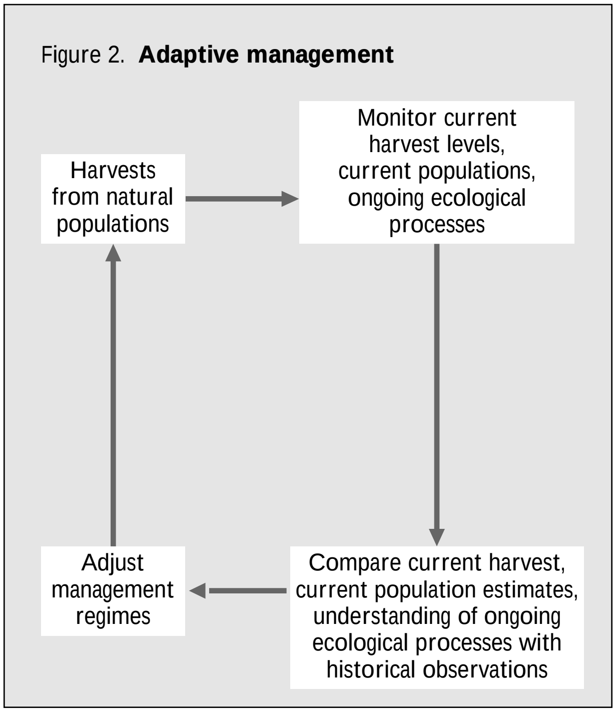
Figure 2. **Adaptive management**

Furthermore, there are strong forces in the modern economy resisting reductions in harvest levels in response to signals of depletion of resource populations. These economic forces take advantage of the uncertainty of the scientific knowledge base of dynamics of resource populations to push for continued exploitation at constant, high levels. In response, scientific management of natural living resources is now turning to a new paradigm, that of ‘adaptive management’, which may be visualized as in Figure 2.

It is evident that historical observations that constitute natural experiments on the natural living resource systems being managed are a critical input to the adaptive management regimes. This is because adaptive management depends on assimilating all available information on locality and time-dependent variation in system behaviour. In many developing countries, large numbers of people are dependent on harvests from natural living resources to sustain their livelihoods. Therefore, in the course of pursuing their own subsistence, these people continually observe the behaviour of the actors on the ecological theatre of their own localities; indeed they accept themselves being one among the company of such actors in the living world. This ‘practical’ or ‘experiential’ (not necessarily only traditional) knowledge is of obvious relevance to adaptive management.

The ‘ecosystem people’, stakeholders strongly dependent on local natural resources for their livelihoods, are being increasingly brought in as partners in programmes of co-management of natural living resources. In this context, social scientists have made major contributions to the design of institutions of co-management. On the other hand, while natural scientists have made some contribution to appropriation of knowledge of ecosystem people as in the development of new drugs, they have made little contribution to developing good systems of co-management of ‘practical’ and ‘scientific’ ecological knowledge. This is a significant challenge for the new millennium.

The overall system of co-management may be visualized as in Figure 3. Such a co-management system calls for a strong mutualistic relationship between scientists and the ecosystem people. A mutualistic relation between scientific and local communities requires that the scientific community appreciate folk knowledge, invariably mingled with folk beliefs, in terms of the categories of objects populating the natural world, as well as the processes operating. It is very necessary that scientists develop an understanding of folk models of specific processes such as the hydrological cycle, or ecological succession, or impacts of human harvests of biomass or fire. In addition, it is important to record location-specific environmental histories, as well as folk perspectives on how natural resources ought to be managed. Such folk knowledge/belief systems will inevitably show tremendous variation over space and among different human communities; the environmental histories too will be highly locality specific, as will be the perspectives on management of natural resources. To record all of this in a comprehensive fashion, and then to establish appropriate links with scientific knowledge, is a great challenge that would have to engage many components of society at large, along with the professional scientific community. Teachers and students in educational institutions at all levels could play a vital role in such an effort; such involvement would greatly enrich their learning experience. This documentation should be an ongoing process, a continual exercise of monitoring the state of the global environment in a highly decentralized participatory fashion.

In India we have made a modest beginning in such an effort through the compilation of People's Biodiversity Registers in 52 village clusters in different parts of the country (Gadgil, 1998; Gadgil *et al.*, 2000). This has met with a very encouraging response from local people, non-governmental organizations, students and teachers, and follow-up programmes have recently been initiated in several hundred localities.

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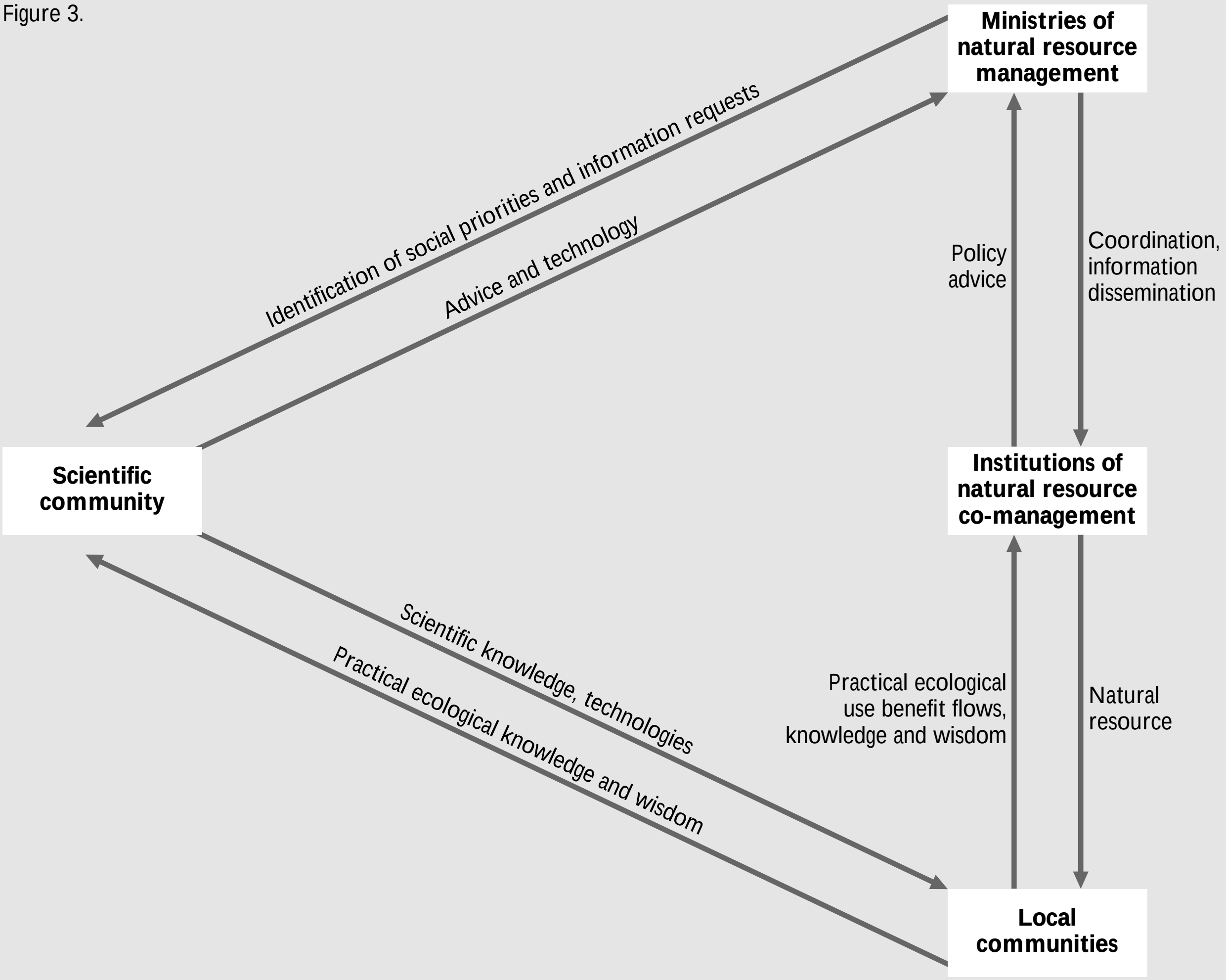
Figure 3.



Fundamental science: a view from the South

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'Creation, mastery and utilization of modern science is basically what distinguishes the South from the North.'

MUHAMMED ABDUS SALAM

What is fundamental science?

I will start with a definition: 'Science is a creative human activity, the object of which is the comprehension of nature, and its product is knowledge, knowledge obtained by means of a scientific method, organized in a deductive manner, that aims to reach the widest possible consensus.' (R. Pérez Tamayo, 1989)

Science is the same for all scientists of all countries in the world: that is why its value is universal.

Why is fundamental science important?

At the beginning of the 6th century BC, the most extraordinary movement of the human mind started in Greece and it is not finished yet: the development of knowledge by rational learning or empirical observation. These humble beginnings led to a rational development of amazing consequences: the adoption by the West of the scientific method in the 17th century. From that moment on, Western civilization would revolve around knowledge.

There have been some who have considered scientific knowledge not an end in itself but a means to dominate nature and to use it for, or against, the benefit of mankind. 'Knowledge is power', as Bacon stated succinctly. Even if scientific knowledge is the same for all scientists, its creation, mastery and use has divided the world into developed and underdeveloped countries.

It can also be stated that fundamental science is important because, based on the experience of the last three centuries, it can be safely predicted that the basic science of today will be responsible for the technology of tomorrow.

Why is fundamental science important for countries in the South?

It is often stated that fundamental science should be carried out only by countries in the North. This has been said by politicians in the North and in the South. The reasons that have been given for this position are many and I will mention only a few: it is expensive; the education system in the South is not good enough; available national resources, if any, should be used for applied science or for technology; the countries of the South do not have the temperament or the culture to carry out research; research is not part of the national identity of countries in the South.

The need for the development of science in Third World countries is imperative for at least the following reasons: to create new knowledge; to have a better understanding of the world we live in; to reduce the gap between Third and First World countries; to improve the quality of the education system at all levels, particularly for undergraduates and graduates; to establish a scientific capability for dealing with pressing problems that may be inherent in a developing country but are of no immediate concern to more advanced countries; to participate effectively in solving the global problems that affect mankind.

The culture, self-image or national identity of a country is the set of literary, artistic and scientific values, together with the uses, habits and activities related to those values. Also included are the ideas, experiences and capabilities common to that society, that provide answers to the following questions: Who are we? Who were our ancestors? How did we get here? Why do we believe what we believe? Why do we act as we act? It also includes the ability to decide the future of our society.

Science is often not considered part of the national culture in countries of the South, not because of a lack of etymological knowledge but because of the scarcity of scientific activity in those countries.

Scientific creativity is part of the human endeavour and we cannot resign as a society from one of the main potentialities of the human being. We should not accept the intellectual bondage that indicates to us that we are incapable of carrying out research, nor the fatalism that leads us to conclude that research is going to be carried out elsewhere and by others, because if science is not thoroughly developed, we are curtailing an important aspect of our identity. Moreover we are leading young people who are interested in scientific careers to think that life happens somewhere else.

The role of science is becoming more and more important in the North. In the developed countries science is considered essential for national well-being and to achieve a brighter future. The support given to science results from, among other things, its ability to deal with the most important human illnesses, compete for the world market in advanced technology and solve environmental problems.

In the Third World we want to maintain our national identity, while transforming it to improve the quality of life of our people. Our identity must be in permanent evolution; we want to keep and nurture positive values, discard negative values and acquire new ones. We need a project for our countries that will allow us to extend and foster our democracy, self-determination and sovereignty. We can conclude that our identity is in an evolving state and not something fixed for ever.

To develop science we need the approval of a significant fraction of the population; this consensus can be obtained by the popularization of science and by the realization that science is beneficial for the development of each nation.

There is no conflict between our national identity and the universal character of fundamental science. To have a national culture does not imply that everything must remain fixed, but that there must be the capability to adapt ourselves to the needs of the community; it implies having the capacity to break with cultural patterns if the people, not necessarily the government, so decide.

Those societies that do not change, do not evolve, are doomed to decline and eventually disappear. Given the innovative character of scientific thinking there is nothing like fundamental science to help to promote positive changes in almost all aspects of our culture. Scientific activity produces a permanent improvement of our world view and a pushing back of the frontiers of knowledge.

How can fundamental science be developed in the South ?

Science can be developed in the South by taking the following five steps.

- Third World countries devote a fraction of their gross domestic product (GDP) to education, their GDP being in general smaller than that of First World countries; moreover Third World GDP per capita is typically 10 to 50 times smaller than that of First World countries. Consequently every effort should be made to increase the fraction of GDP dedicated to education. In other international meetings it has been recommended that Third World countries aim for an expenditure on education of 8% of GDP. François Mitterrand used to say that ‘Without teaching, higher education and research the Nation would not have anything.’
- The quality of Third World scientists is comparable to that of their First World counterparts, but the number of scientists in Third World countries per million inhabitants is 10 to 30 times smaller than in First World countries. To bridge this gap each underdeveloped country should adopt a long-range programme to increase the number of scientists at a yearly rate of at least 7.5%.
- Third World countries in general spend less than 1% of their GDP on research and development (R&D), whereas First World countries expend between 2% and 3%. Considering the difference in income between the South and the North, it follows that typical Third World countries invest from 30 to 300 times less per capita on R&D than First World countries. We should start immediately to increase our expenditure on R&D and aim for an expenditure of 1% of GDP in the short term and 3% in the long term.
- To have productive science we need high-quality training including modern instrumentation. One of the reasons why some Third World students do not come back to their countries of origin is the lack of modern instrumentation. Often, long-range planning is non-existent in Third World countries. It is necessary for our countries to allocate resources to acquire and build modern research instruments. These instruments should be available to all national researchers and their international collaborators.
- To bridge the gap between Third World and First World countries it is paramount to internationalize our scientific activities. One of the characteristics of our scientific activity is its inbreeding or endogamic nature, due to our isolation and the small number of scientists working in our countries. We have taken some steps to remedy this problem. For example we have established scholarship programmes to send graduate students to obtain their PhD degrees in the North. Due to the brain drain there have been some voices raised in favour of reducing the scholarship programmes to study abroad. I consider that these programmes should not be curtailed and that we should send some of our students to do their graduate work abroad. We should not worry if a few of our scientists remain abroad as long as a similar number of foreign scientists decide to emigrate to the South.

In addition I consider that we should broaden and enrich other types of measures to fight inbreeding in the South. For example, we should promote the incorporation of foreign students into our graduate programmes; invite foreign scientists of a high quality to work in our countries for a short time or even permanently; participate in multinational research groups; share our facilities with researchers from all countries of the world and ask all countries of the world to reciprocate.

Conclusion

Due to our colonial past, a significant fraction of Third World inhabitants reject ideas coming from the First World. They consider many aspects of Western culture as the root of oppression. We should distinguish between scientific knowledge and ideologies that pretend to control and dominate other countries. We should participate in the development of science and use it for the well-being of the people of all nations. The future of mankind is one, many of its problems are global and solving them requires the active participation of all countries of the world.

Thematic meeting report

Ian Butterworth
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In his introductory statement, Hubert Markl said that it was often very difficult to distinguish between fundamental and applied science, and therefore it was probably more useful to slightly retitle the session ‘The universal value of scientific knowledge’.

He recalled that Robert Merton has argued that scientific knowledge is universal as a consequence of four characteristics.

- The impersonality of that knowledge; its independence from the observer. Scientific discoveries may result from the work of gifted individuals, but once established scientific knowledge is impersonal, usable by anyone.
- The communicability of that knowledge. Science is fundamentally a collaborative venture. If a person knows something in secret then that is not science.
- Disinterestedness. The outcome of scientific investigations is unaffected by the wishes or fears of the scientist.
- Organized scepticism. Scepticism implies openness to new insights and to criticism; scientists can never accept the concept of an absolute truth. It is necessary for scepticism to be formally organized, since individual and successful scientists can all too readily overvalue the validity of their observations or thoughts.

To maintain these characteristics requires freedom of thought, knowledge and speech – such freedom is not just a privileged reward for the scientist but a requirement for the creation of scientific knowledge.

These characteristics describe scientific knowledge, but Hubert Markl stressed that he was concentrating on the natural sciences. In the social sciences and humanities, tradition and belief can be very important and it would be inappropriate to demand all aspects of the scientific method as used in the natural sciences. It would also not be appropriate to assume that scientific knowledge is the only form of knowledge.

Mohammad A. Hamdan, Jordan, spoke on ‘Science as a productive force’ in society. In primitive agricultural societies, productive activities depended on intuitive or experiential knowledge, but with the modern era science has moved from the periphery of culture to its centre and is now the major productive force. Science has become a condition for modern survival. But science is an open totality, a complex organism which cannot be treated in a fragmentary way.

The World Conference on Science is an opportunity for all nations to reconsider their priorities and to recognize the universal role of science in dealing with world crises and enhancing the quality of life for humankind. We look to science as the foremost tool to allay many global threats like climatic change, environmental degradation, etc.

Governments play a pivotal role in the support of scientific research, since private sector support is usually concerned with short-term research of direct commercial benefit. Governments must take a far-sighted view and support pure science. History is full of cases where the pursuit of pure science subsequently led to entire fields of practical application. Regional and international cooperation is essential for an equitable global give-and-take providing a foundation on which nations can build to escape from poverty and dependence.

New conflicts can result from growing global inequalities which in the future will inevitably be defined by response to advanced science and technology. Each developing country has to have an endogenous capacity to compete globally. Science will mark the future status of nations.

But scientific research must safeguard human dignity, for example in genome research. The needs of future generations and the ethics of science have gained increased significance. It is extremely unfortunate that there has been a steep increase in military research and development (R&D) in industrialized countries to the detriment of fundamental research and it is appropriate that the United Nations has proclaimed the year 2000 as the International Year for the Culture of Peace. The international scientific community can play a constructive and beneficial role in the culture of peace – just as science has advanced to such an extent that a major conflict could erase life from Earth.

Madhav Gadgil, India, spoke convincingly of the need to forge an alliance of formal and folk ecological knowledge. Back in 1976 he had had discussions with users of trained elephants in the forest who recognized that, though elephants liked the leaves of *Ficus* trees, the local practice was to strictly protect *Ficus* trees, the fruit of which they realized was an important food for birds, bats, squirrels and monkeys. However, the protection was explained by the belief that *Ficus* trees are the abode of nature spirits. When 10 years later the concept of keystone resources for biodiversity was discussed by scientific ecologists, it was argued that one such keystone was the *Ficus* tree. He thus realized the possibility of such an alliance between formal and folk knowledge.

In complex systems it is not easy to obtain experimental evidence for a formal scientific ecological position; there are just too many parameters. Yet, in practice, we have to manage living resources, for example in the very important issue of the control of fish stock. A new approach would therefore be co-management of resources in a partnership between scientific ecologists and locals maintaining traditional views. Such collaboration can be difficult since local views mingle knowledge and belief, but in a complex situation that view can perhaps be thought of as the result of long experience and may be more effective than ill-defined quantitative approaches. To be effective, it is important that a significant number of those from the scientific side be themselves from that geographical area and acceptable to the local community. Once the members of that community see that their knowledge and understanding are recognized, they are able and willing to work as partners.

Those at the session felt that this could be a convincing approach in many areas of resource management and should be encouraged. Manuel Peimbert, Mexico, discussed the view of the universal value of fundamental science from the South.

Fundamental science is important, since the fundamental science of today leads to the technology of tomorrow. Some have argued that the creation of fundamental science should be left to the countries of the North, since it is expensive and resources would be better invested elsewhere. Manuel Peimbert argued strongly against that position. Involvement in fundamental science not only creates knowledge but leads to a local understanding of the world, improves education and reduces the North-South discrepancy. It is essential to maintain a scientific capability in order to deal with problems peculiar to the South. It is important to the national self-image to be able to play a role in the global scientific endeavour.

It is therefore essential that governments in the Third World:

- increase educational funding as a proportion of gross national product (GNP);
- increase expenditure on science and technology as a proportion of GNP.

It is sometimes felt that, because of their poverty, countries of the South cannot do these things, but it is the way to improve the situation. Funding should be appropriate to the GNP. The First World spends 2% of its GNP on R&D. The Third World must have an immediate goal of spending 1% of its GNP on R&D and a long-term goal of 3% as a way of raising the economy.

The funding of local instrumentation is important, since inadequate local facilities discourage the return of young scientists who have gone to the North for training. Good facilities will encourage a flow of scientists from Northern countries to spend time in the South.

In discussion, there was some concern at the use of the terms ‘North’ and ‘South’. Geographical discrepancies are more complex. Collaborative research between countries of the South was important to enhance local facilities and to reduce undesirable migration. Some aid agencies have tried to force Third World research groups to concentrate on applied science and avoid basic science. It is a very bad position; if there is no effective local science base then there is no-one capable of giving local advice. It is essential not only to have local experts but also for them to be clearly perceived as experts.

The general view from the meeting was that the term ‘brain drain’ was an unprofitable catch phrase. It is of the nature of science that there should be a flow of brains between countries, but we have to encourage a balanced flow over the long term. Indeed it was the very strongly held view of the meeting that, just as it is now largely recognized that higher education is a human right, the World Conference on Science should acknowledge a further human right: that any scientist has the right to develop his or her scientific skills and ability to the full. The development of scientific ability must not be hindered by geographical location.

Catherine Brechignac, Director-General of CNRS, gave some examples of the way in which fundamental science may develop in the future. One is the Pierre Auger Observatory to study the origin of ultra-high energy cosmic rays, which involves a 6 000 square kilometre detector complex being developed by a global collaboration of 19 countries from both the industrial and the developing worlds, though sadly with none from Africa. Major changes are taking place in the life sciences, for example in the study of pathogens. Like other speakers, she pointed to the difficulty in drawing a clear line between pure and applied science. Despite that, an important issue for science policy is how to determine the balance in funding between that research which is primarily for knowledge-building and that which is to be performed primarily to strengthen the economic and social base, and who should determine that balance?

In the overall discussion, a view was expressed that there was a very real danger of a reduction in funding support for basic science. All too readily, governments and companies can say ‘get someone else to do it’! Basic science should be seen as a public good and all governments should pledge to contribute to that general knowledge.

As a general good, the results of fundamental science should be available to all. Attempts to limit access to that knowledge for society as a whole by patenting or other intellectual rights limitation should be resisted.

Introduction

Abdulaziz Othman Altwaijri
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Assalam alaikum warahmatu Allah Wabarakatuh

It is indeed a great privilege for me to attend with you this thematic meeting on the theme of Science in Response to Basic Human Needs, which is being co-sponsored by the Islamic Educational, Scientific and Cultural Organization (ISESCO) as part of the World Conference on Science; and I wish you success in addressing this vital issue within an all-embracing vision in order to come up with sound proposals and solutions.

One of the greatest disparities among nations and peoples in the world is due to differences in education and training standards and facilities available to the public. The lack of access of a large percentage of the population to basic education and the failure of millions of others who complete primary education to gain any international standard in skills and abilities has become a major hurdle in the development process and a burden on the economies of developing countries. It is necessary to address these problems urgently through joint efforts and international partnership.

Further, the size of the technically skilled workforce and qualified scientists available in the developing countries is not sufficient to support economic development. It is necessary for these countries to intensify human resource development efforts in areas of critical importance keeping in view the future needs.

Due to magnificent scientific and technological successes in attaining prosperity in the developed countries, the need to utilize these results in the developing countries to solve the basic problems of deprived populations has increased now more than before. The right approach for industrialized countries and international agencies at this historical juncture is to extend generous support to enhance the necessary capability of these countries especially to address issues of development, sustainable resource management and people’s basic needs such as health and education. Advances in new fields of technology offer tremendous opportunities and inexpensive solutions to most urgent problems in the agriculture, health, energy and environment sectors. It is necessary to provide development assistance to the developing countries to utilize new technologies to solve their specific problems in a sustainable way.

Though agriculture is the mainstay of the economy in many developing countries, the latter face extreme difficulties in feeding their own people and import basic food products, something which constitutes a heavy burden on their respective economies. Developing countries can reduce hunger and improve their access to food supplies through increased investment in agricultural research and development. The developing countries, therefore, need to give special consideration to advanced techniques such as farming innovations, cropping patterns, new methods of irrigation and fertilization. Management of water resources is an important necessity for the developing countries to increase their agricultural output and to utilize them as efficient renewable energy resources. Foreign assistance programmes are necessary to support the hydrological projects and investigation of new water resources, especially for attaining self-sufficiency in food production.

Science is the most effective tool for alleviating human suffering and meeting basic human needs. Balanced development is an essential means of achieving this objective. For the affluent societies, science and technology (S&T) produce more economic gains and comfort in people’s lives. However, for the less-developed nations, their only hope if they are to ameliorate their socio-economic conditions is for them to face the challenges of their own survival in the coming century. The need to utilize scientific and technological knowledge to address the challenges of food shortages, ill health, pure drinking water, housing and illiteracy has never been so acutely felt before. The World Conference on Science has provided us with an opportunity to discuss and debate ways and means of reducing disparity among and within nations and of reaching a common framework for action for a more equitable, prosperous and sustainable future in the next century. I am fully confident that, by the Grace of Almighty Allah, your deliberations will help us to address today’s challenges and draw up a realistic action plan as the beginning of a brighter future for the next generations.

I thank you for your attention and wish your deliberations every success.

Assalam alaikum warahmatu Allah Wabarakatuh

Scientific capabilities in the research on basic needs for development

Eduardo Moacyr Krieger
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Science is an essential means of meeting society's needs for food, water, energy, health care, shelter, safety and alleviation of poverty.

Scientific research does not operate in a void. Science is produced through the existence of the so-called 'scientific establishment', formed by the group of institutions, persons and resources directly involved in the production of new knowledge according to certain 'internal' rules and procedures.

Since its inception science, as we know it in the West, has been characterized by a set of principles that define the scientific ethos: universalism, communism, disinterestedness, organized scepticism. Unfortunately this conception of science contributed to isolating scientific activity from other dimensions of social life and to creating the myth that science should not be subject to any kind of social control or should not be asked to respond to social demands other than the enhancement of the understanding of the universe.

Much more recently, we all became aware that science, as other social activities, is the product of the interaction of a complex set of factors that must be understood both in its internal logic as well as in its relation to other fields of human activity.

Until the First World War, the link between science and technology was not perceived as a fundamental one. Science was considered part of the domain of culture while technology was in the sphere of economics. In-between lay the field of the applied sciences where part of the effort of the scientific community was directed towards the punctual solution of specific problems in the fields of public health, agriculture, energy production and so forth. Both in developed countries and in the developing world, applied research was developed mainly in research institutes and only eventually at the universities.

For a long time, pure science was considered a free enterprise of the human spirit and scientific knowledge was valued as a common good that should be available for all humankind, whereas technology was viewed as being directly related to the need to improve processes and products. Actually, whereas new scientific achievements were considered as public goods, new technologies resulting from private investments were subordinated to the rules of the market and subject to property rights regulations.

After the Second World War, the unprecedented advancement in technology – based on scientific knowledge – demonstrated that the relationship between science and technology was not fortuitous. This resulted in a widespread creed that, to reach social and economic development, every nation needed to invest in the creation of a solid scientific foundation as a prerequisite to achieving technological independence and to attaining the capacity to solve the problems that afflicted their societies. Science began to be valued as the primary answer to all human problems.

This new approach also impelled the belief that, in order to attain this objective, it was necessary to generate a 'critical mass' of scientists and that the education system was a fundamental tool for creating the preconditions for this endeavour. Developed countries – which did not face illiteracy and already had strong education systems, at all levels – were those where the advances in science were taking place thus demonstrating the basic role of education.

Regarding this fact, several nations in the South began to invest in the establishment of their scientific capability, through the creation of graduate courses or the establishment of training programmes abroad, in order to bridge the gap that separated North and South. Several countries in the developing world were quite successful in creating their own systems of science and technology (S&T) and in training a considerable amount of scientists. Despite these investments, this effort did not result in the automatic solution of the most serious social and economic problems in the developing world. Science *per se* was not the key for development.

It was soon discovered that, instead of a causal relation, the links among science, technology and innovation were far more complex and depended on a much wider set of factors than initially thought: the path between scientific discovery and technological innovation was not linear.

As recognized in the draft *Declaration* of this Conference, besides contributing to the improvement of human life, scientific and technological development also brought about unexpected consequences: environmental degradation, an uneven distribution of its benefits and the widening of the gap between industrialized and developing countries. Even in the developed world the benefits of science began to be questioned.

We are here to discuss a new commitment on a world scale. However, for us in the developing world it is paramount to establish our own agenda.

First of all we should be aware that we must unite our efforts in order to enhance our endogenous capacity to generate our own solutions to our own problems. This implies that we must orient our efforts towards the establishment of a set of priorities that take into consideration our specific needs and not only reflect those priorities that are fundamental in the North. Nevertheless this does not imply that we should give up the intent to participate actively at the frontiers of science or encourage the extinction of our incipient scientific communities. The challenge is to redirect the institutional and intellectual assets that we possess into a new role adjusted to the globalized world, without having to start again from scratch.

Our actions must be threefold: on the one hand we have to pursue our efforts to strengthen our national systems of S&T, in order to be able to consciously generate, import, adapt and disseminate new technologies. We need to learn how to make more effective the partnerships among the actors and institutions of the system, to avoid the squandering of resources and to facilitate the conversion of scientific knowledge into practical actions or new products. We have to identify institutional arrangements and incentives more conducive to innovation.

This strategy, however, depends on a strong scientific basis directly linked to a strong education system, on both national and regional scales. To recognize that education at all levels should be given priority is to recognize that, if one has a broad and sound educational basis, that will be inductive of high academic achievements at the apex. In order to keep control and reap the benefits of scientific and technological knowledge it is fundamental to develop the ability to absorb the existing knowledge, to create new things or to put old things to better use.

For this, what matters is the implicit and tacit knowledge of educated populations, that is to say that the main aspect of science policy in the coming century for countries both in the North and in the South should be policies for education, dissemination, networking and communication, rather than policies for the development of specific products or for the particular interests of the self-contained scientific communities. A good education system is the only way to make sure that a nation has the capacity to hold to these goals permanently, that is to say to maintain its capability to use scientific knowledge and technological innovation.

The creation of scientific networks in the South also represents an alternative for overcoming the shortage in scientific personnel and facilities in some areas. Scientific cooperation with developed countries must also reflect our own realities and must be reoriented regarding our own interests.

The second item that must be present on our agenda comprises scientific cooperation besides South-South cooperation, which is fundamental to strengthening our capacity in those areas of basic science. We must rethink our relationship with the North: we do have in some areas the possibility of generating mechanisms of cooperation based on new grounds, such as the use of our biodiversity. A recent and successful experience fostered by ICSU's Committee on Science and Technology in Developing Countries (COSTED) was the creation of an International Interdisciplinary Research Network on Bioactive Natural Products. The networks of COSTED/IBN also represent an important instrument for implementing international cooperation. They are also a most valuable proactive action to create local conditions for scientific research and consequently effectively avoid 'brain drain' from developing countries.

Finally, we must face the fact that the solution to our social problems will depend on our capacity to establish a strong commitment by our national scientific communities to questions that affect us in the fields of health, education, food production, sanitation, energy conservation, among others. In this case, governments may play a decisive role when different ministries and local governments increase their support for endogenous solutions and recognize that sustainable development requires intense research and specific technologies that may be developed or adapted nationally or regionally.

National or regional science exists when national or regional problems are treated according to the best standards of international science: the objects may be particular but the methods must be universal.

These are a few ideas that in our view must be given a privileged place in our future discussions. Let me now give some Brazilian examples for these ideas and refer them to the Conference documents.

Science in response to basic human needs

'…without adequate higher S&T education and research institutions providing a critical mass of skilled scientists, no country can ensure genuine development' (para. 23 of *Introductory Note to Science Agenda*).

The efforts developed by the Brazilian Government in order to strengthen our national capacity in science presented very good results. We may see that the participation of our country in international science increased from 0.4% in the early 1980s to 0.9% in the late 1990s, according to the Institute for Scientific Information (ISI).

Importance of university research to build a national S&T system

- to assure science education in all levels;
- to provide the scientific base for professional education (medical doctors, engineers, biologists, etc.);
- to generate, import, adapt and disseminate new technologies;
- to promote university-industry cooperation.

Scientific cooperation to strengthen the national S&T base

- to increase the exchange of knowledge;
- to strengthen the links between local, national and international research institutions;
- to increase international postgraduate training (priority for areas of socio-economic relevance);
- international projects with international financial support;
- role of networks of science (ICSU-COSTED/IBN-TWAS-unions-academies).

Socio-economic relevance of science

The efforts to strengthen national systems of S&T must be associated with an increasing commitment by the national scientific communities to questions that affect each country in the fields of health, education, food production, sanitation, energy conservation, among others.

Science, technology and innovation

'Even in those countries that have managed to build up a critical mass of scientists, the scientific system is weakly linked to the productive system and local industry is far from benefiting from opportunities created by S&T. As a result, S&T do not contribute to the creation of national wealth in these countries.' (lines 231-235 of the draft *Science Agenda*).

Brazil has been steadily increasing the number of PhD graduates during the last 37 years: 3 500 doctors in 1997 compared with 500 in 1960. However, when we compare these data with the Republic of Korea and the USA we see that these doctors are mostly at the universities and very few are absorbed by industry: 72.9% in Brazil, 35.1% in Korea and 13.4% in the USA.

Major challenges for S&T in developing countries

- to promote universal education;
- to increase the number and the quality of the personnel engaged in S&T;
- to increase linkage between the university and the productive sector, public/private, to use knowledge for the benefit of socio-economic development;
- to increase the percentage of S&T investment in relation to the gross national product (GNP), with greater contribution of industry;
- to promote simultaneously basic science and strategic S&T projects with socio-economic impact;
- to achieve sustainable development and to preserve the environment.

Essential national health research, a powerful instrument in response to basic human health needs

Esmat Ezzat
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Basic minimum needs (BMN) approach

Looking at our immediate experiences and realizing the short time left until the year 2000, we should analyse and solve the problems that are slowing progress towards HFA (Health for All)/2000. There are three major categories of problem:

- First, there has been less realization of the health development equation: which consists of provision, means and recipients. International agencies and governments have invested in developing provision/providers/potentials but the recipients (i.e. people) have been neglected, resulting in many of them being dependent, passive and leading negative lifestyles.
- Second, in many countries implementation of HFA/2000 strategies encountered weaknesses in the areas of management, resources, community involvement, intersectorality and coordination.
- Third, there has been a universal realization that health cannot be achieved in the absence of satisfaction of basic

needs of life (basic education, housing, reasonable income, water, food, security, etc.).

The challenge is evident and the solution is clear. We need a programme that will meet BMN, solve HFA implementation problems and develop the attributes and qualities of human beings. I am pleased to introduce the attributes and Quality of Life (QOL) programme, already tested, and a research approach that defines its applicability as a new paradigm for accelerating the implementation of HFA/2000 strategies and ensuring success.

Up until 1987, the QOL programme used the BMN approach, which is a process of organizing and mobilizing community members to realize their health and development needs and work collectively to achieve them. It is a community-based, community-managed and community-financed programme.

An evaluation of the pros and cons of BMN programmes was performed in 1990 and the findings were: BMN is a concept that aims to achieve a better quality of life; it is a participatory, dynamic process of integrated socio-economic development, based on self-reliance and self-management by organized communities supported through coordinated intersectoral action.

The development of health care systems so far has emphasized an input and output relationship. The perspective was to build infrastructures and seek quick returns. It was believed that quick returns, as well as quantified outputs, were favoured by decision-makers. Little emphasis was placed on the process. Within the process, little attention was given to developing a ‘recipient’ capacity.

BMN tried to correct this deficiency and, by investing in community human resources, a more lasting situation was achieved: attitudes and attributes of the human element were changed and thus behaviour and action were more conducive to rational and better decision-making for development.

The BMN approach is an evolution. It should not be sold as a new concept, replacing the existing systems and approaches. BMN allows the community to meet the challenges of today, be they financial, organizational or attitudinal. The investment has so far been in the provision of care and it has meant that the most important element – i.e. ‘people’ – was neglected. People were always treated as recipients and objects. BMN provided remedies to these problems through changes to organizational, attitudinal and financial systems at the community level, and through building on these changes.

Major progress has taken place during the past 16 years in implementing the BDN (Basic Development Needs) programme among the Member States. Thirteen countries are at different stages of implementing the programme. This approach has also been adopted formally as a national development strategy in some countries. The programme has achieved success in attracting new partners among international agencies and non-governmental organizations (NGOs). There has been, over the years, considerable sharing and exchange of experience among Member States; many study tours and field visits have been organized to successful BDN sites.

Achievements

A high degree of community mobilization, organization and empowerment was achieved: intersectoral collaboration was greatly strengthened through the BDN teams. Community structures were established for the promotion of solidarity and democratization. Increased coverage and accessibility to essential public health services, such as immunization, family planning and maternal and child health, were achieved through improved delivery of health services and human resource development. A wide range of income-generation activities was initiated supporting agriculture, livestock, small business and handicraft schemes. This led to higher income levels and better nutrition. The BDN process gave special emphasis to mobilizing and empowering women. Considerable attention was given to schemes for improving education, particularly for girls, and women’s development. Communities attained self-reliance, even in difficult situations involving war and civil conflict. More than half of the Member States of the region have initiated BDN programmes. BDN projects at the country level succeeded in obtaining support from different partners. BDN successfully demonstrated its applicability to both rural and urban areas.

Constraints

- inadequate operational research and documentation;
- general lack of systematic approach to planning, management and evaluation;
- difficulties in obtaining financial support from governments;
- lack of adequate experience in management of micro-credit schemes;
- insufficient support from other United Nations agencies and international organizations;
- difficulties in establishing effective partnerships with NGOs and academic institutions;

- inadequate training of BDN team members; lack of training material and modules particularly in local languages;
- lack of effective promotional material for BDN and of published reports.

Conclusion

BDN is open and inclusive of informed choices made by the target communities. There is unanimous agreement that measurements are needed to document evidence of success for the purpose of advocacy and promotion. Documentation and promotion of BDN should be based on evidence. For the sustainability of BDN initiatives a multitude of factors should be considered, such as financial procedures, community capacity-building, government support, intersectoral collaboration, institutional arrangements and continuity of community interest in BDN. The BDN planning and implementation schedule should indicate a specific time-frame and duration after which the active involvement of the external initiator (e.g. World Health Organization) would be scaled down. Stronger links should be sought with United Nations agents at the country as well as the regional level. Full compliance with administrative and financial rules and regulations should be ensured.

Tools for monitoring and evaluation of BDN programmes, process and outcome measures should address the following areas: poverty reduction, community organization, intersectoral collaboration, partnerships, health, education, nutrition, women's development, water and sanitation, income generation, financial aspects, promotion and advocacy.

The actions to strengthen future BMN initiatives in the region are grouped here under three categories:

- streamlining BDN planning, implementation and evaluation processes;
- strengthening advocacy and partnership efforts;
- enhancing capacity-building and training activities.

To avoid and overcome negative aspects of BDN, health research varieties, mainly Essential National Health Research (ENHR), were introduced by Health Research and Development in 1987 in an effort to rationalize research as a tool for health development.

Definition of Essential National Health Research

ENHR is an integrated strategy for organizing and managing research, whose defining characteristics include its goal, its content and its mode of operation:

- ENHR's goal is to promote health and development on the basis of equity and social justice.
- ENHR's content includes the traditional types of research commonly described as epidemiology, social and behavioural research, clinical and biomedical research, health systems research and policy analysis; but it is specifically oriented towards the most important problems affecting the population, with particular emphasis on the poor, disadvantaged and other vulnerable groups whose health needs are often overlooked or ignored.
- ENHR's mode of operation is characterized by inclusiveness, aiming to involve researchers, health care providers and representatives of the community in planning, promoting and implementing research programmes.
- ENHR should promote multidisciplinary and intersectoral research, the results of which are effectively translated into action; objective scientific analysis guides policy and action.
- ENHR implies the use of scientific methods to analyse health situations, identify problems and solve them. The essence of ENHR is an intersectoral, multidisciplinary scientific approach to health programming and delivery.
- ENHR was conceived as a corrective tool for frequent points of failure in existing research systems:
  - policy-makers often do not make use of research findings in decision-making;
  - managers of health care programmes do not always use research results, nor do they apply scientific methods in planning, monitoring and evaluating services that they deliver;
  - researchers often do not address the health problems that are perceived as top priorities by policy-makers, health care managers and people.

ENHR strives to identify the main diseases and conditions that continue to place an unnecessary burden on society, to assess the effectiveness of control measures and to identify technical and cultural obstacles to successful implementation of health programmes. Examples are:

- *Patterns of health and disease*: common causes; mortality and mobility in various sub-groups of the population.
- *Determinants and risk factors*: geographical, environmental, economic, social and behavioural factors that influence incidence, prevalence, severity and outcome of specific diseases and conditions. The most important risk factors in the occurrence of common cancers, sexually transmitted diseases, abuse of alcohol and illicit drugs, and other major health problems.
- *Operation and utilization of health services*: immunization of children according to the recommended protocol;

proportion of pregnant women who receive prenatal care; demand for and utilization of prenatal services; means available to enlarge the number of households that have access to a safe, protected water supply; effects of policies outside the health sector – agricultural, economic and educational – on the health status of the population.

Types of ENHR

ENHR includes two complementary kinds of research effort: country-specific health research and global research.

Major ENHR strategies

One major challenge in developing ENHR is to generate problem-solving and action-oriented research programmes that will tap the skills and knowledge of scientists from a wide range of disciplines. The other challenge is to create a dynamic process linking policy, action and research.

Intersectoral and multidisciplinary approach

Problem-driven and action-oriented, ENHR would deal with any health problem that burdens people in the country, with the objective being to lessen the level of disability and death it causes.

International implications

Country-specific research would generate scientific and locally relevant knowledge that governments, health care providers and people need in order to articulate their problems and to determine national research and action plans. They give developing countries a stronger voice, empowering them to express their priorities in international forums.

Expected contribution of ENHR

To understand the country's own problems, to improve health policy and management, to foster innovation and experimentation, leading to:

- health information and situation analysis;
- enhanced impact of limited resources;
- promotion of global health research.

The seven elements for implementing ENHR

1. ENHR promotion

Research on health in developing countries suffers serious constraints, including limited opportunities for career advancement and professional development, weak and unstable institutional environments and insufficient and erratic funding. The lack of perception of the importance of research has resulted in low social esteem and poor salary structures for scientists.

2. National ENHR mechanism

The linkage between research and the utilization of research results needs to be strengthened through greater participation of research users in setting the objectives and timetable for research projects and through more effective communication of results to potential users.

3. Setting priorities for the ENHR action plan

Each country should develop a strong plan to conduct research on both country-specific and global health problems, a plan that is feasible, economical and coherent and that involves all relevant groups.

4. Strengthening research capacity

Implementing a national plan to conduct research on both country-specific and global health problems will require building and maintaining research capacity within developing countries and sustained reinforcement from the international community.

5. Networking

Nurturing individual scientific competence and leadership; strengthening institutions, establishing strong linkages between research and action agencies; and reinforcing national institutions through international networks are all important elements of capacity-building.

6. Mobilizing financial resources for ENHR

The proposed expansion of research into health problems of developing countries will require a substantial increase in funding. Developing countries, bilateral and multilateral development agencies, industrialized country research agencies, foundations, NGOs and the pharmaceutical industry all raise funding levels for health research.

7. Evaluation of ENHR

Challenge ahead

The national ENHR plan must be creative, well adapted to local circumstances and sustainable: ENHR poses complex problems and there is no blueprint for dealing with them.

- How can the delicate balance between researchers' independence and their need to respond to national priorities be maintained?

- How can one ensure that the political process involved in defining priorities is democratic?
- How can the reliability and inclusiveness of the information base be improved?
- How can power struggles among individuals and institutions in the country be minimized?
- How can peer review systems be established?
- How can the donor's control over the research agenda be reduced?
- What are the best schemes for developing research capacity?

Bringing research closer to the political process also carries implications for the autonomy of researchers. A balance must be established between researchers' activity and their need to respond to national priorities. It is fundamental to ensure some degree of independence and sometimes dissidence of researchers in each country, since the independent pursuit of research can lead to important breakthroughs in the social and physical sciences, and make essential contributions to health and development.

The challenge for industrialized countries is to strengthen and sustain international ENHR movements. ENHR internationally holds out great hope that the fledgling movement being fostered by developing and developed countries alike will live a long and prosperous life for the benefit of humankind.

Development of biotechnology applied to food and health, to face basic human needs in developing countries

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The world population continues to grow at 1.5% a year and it is projected to reach 8 billion by 2020 and 11 billion by 2050. Almost all this growth will occur in the already overpopulated, underdeveloped and poorer regions of Africa, Asia and Latin America, which will shelter nearly 90% of the human population. Demands for food in the most populated parts of the world will double by the year 2025 (Sasson, 1990). Science and technology are lagging behind in developing countries. To overcome this situation, there should be real change. The problems to solve are the following: lack of meaningful commitment to science, be it basic or applied; no commitment to self-reliance on technology; inadequate institutions; inappropriate ways of managing the scientific enterprise; the uncaring attitude of the suppliers of technology and of the North towards technology transfer to the South; and lack of stability in science policy (Salam, 1990). Developing countries are facing the following three main challenges: food supply, health improvement and environmental protection. There is no doubt that biotechnology is nowadays a real possibility for overcoming these problems (Mateo Box, 1993; Quinteros, 1997; Jaffé, 1991).

The food problem

Application of biotechnology in response to basic human needs regarding food in developing countries is real at present. There are different approaches such as the development of plant biotechnology, biotechnology applied to livestock production and biotechnology applied to food processing.

Plant biotechnology can offer an important solution either through the application of conventional methods or with modern methods, or mainly with the proper combination of both (Sasson and Costarini, 1997). It is claimed that conventional methods will not be able to satisfy the appropriated production demand worldwide. Nowadays transgenic crops are increasing very rapidly. This market is expected to grow from US$ 450 million to over US$ 7 billion by 2005. The main genes integrated into crop species to produce transgenic plants provide resistance to many pests, pathogens and herbicides as well as resistance to stress such as temperature, drought and salinity. Among these, the following can be mentioned: genes for improving crop productivity, genes for production of health products and genes for manipulating starch, proteins and oil. In the developing world several factors or problems which might influence the development of biotechnology ought to be taken into account, including:

- *political*: about 8% of Latin American owners own 80% of the land;
- *economic*: lack of financial support to the peasant to buy tools, seed, fertilizers;
- *social*: closer links between peasants and the new agricultural technologies must be developed.

It is important to consider the concern over consumption of transgenic crops. Nevertheless, it is also very important to take into account the responsibility of the work done by scientists all over the world and also the methods of quality control and quality assurance developed.

If one figures out that today 800 million people suffer from malnutrition in developing countries, where food imports are expected to double in the next 25 years, we come to the conclusion that transgenic plants could offer developing countries an opportunity to increase domestic local food, feed and fibre production by 10-25% in the next decade. Other considerations that underpin the strategic importance of transgenic crops for developing countries are the following: the area of almost all crops is far larger in developing countries than in the USA and Canada, where adaptation has been higher to date – for instance, 145 times more rice, five times more cotton, three times more corn. The yields of almost all crops are significantly lower in developing countries than in industrial countries due to pests, weeds and diseases. The global area cultivated with transgenic crops by the end of 1998 was 27.8 million hectares and the distribution by countries was: USA 74%, Argentina 15%, Canada 10%, Australia 1%, Mexico <1%, Spain <1%, France <1%, South Africa <1% (James, 1998). As we can see, most of the growth is in the developed world. There is something that should be clarified: the concept of scientific development. We are not saying that it is compulsory for developing countries to work on transgenic plants but these countries are not doing well in their own scientific development and, if they do not pay attention to this problem, the existing gap that grows every day between developed and developing countries could lead to a situation in which they would not be able even to understand how behind they are and what should be done in order to combat the scientific underdevelopment that these countries are suffering from.

In Cuba a wide programme in biotechnology was developed with important outcomes in different areas. Plant biotechnology started in the 1980s and the situation nowadays is that there are pilot studies in such transgenic crops as sugar cane, potato, sweet potato, papaya and also different stages of development in rice (resistance to insects), potato (resistant to fungus and tolerance to glufusinate), coffee (resistance to insects), citrus (resistance to viruses), corn (resistance to insects and tolerance to glufusinate), tomato (resistance to virus), pineapple (resistance to viruses, fungi, insects and tolerance to glufusinate), and sugar cane (reduction and/or modification in the quantity of lignin for animal feeding).

Livestock production, in many circumstances, is not completely applicable to Third World biotechnological use. However, it is important for animal health applications such as diagnostic means, new vaccines (recombinant cattle tick vaccine, recombinant vaccines against colibacilosis and others), application of somatotrophic hormone to increase milk production, improvement in animal feeding and animal reproduction, such as embryo transplantation. The production of transgenic animals and animal cloning brings about a new dimension in animal biotechnology for different purposes. In Cuba there are recent developments with transgenic fish with a speed of growth even twice the normal strain, creating a real revolution in this field (Hernandez *et al.*, 1997). Considering the status of science (and other characteristics) in developing countries, a tentative approach to procedures to improve nutrition by using animals could be rated as follows: 1) procedures of genetic improvement (mainly in cattle); 2) embryo transference (mainly in cattle); 3) prevention of diseases such as foot-and-mouth disease, bovine plagues, brucellosis, peripneumonia, tuberculosis and parasites; 4) vaccination against different diseases; 5) intensive fish breeding in ponds; 6) other procedures such as growth hormone for the improvement of milk production in cows; 7) transgenic fishes with a higher speed of growth than normal species; 8) modern techniques for diagnosis of diseases in animals; 9) modern scientific approaches such as transgenesis and cloning in animals. There are procedures for food processing with application in any country for detection of pathogen contamination, for the production of enzymes for different purposes, for the use of micro-organisms in food conservation and for micro-algae crops.

The health problem

Biotechnology applied to health in developing countries is a special chapter. The main difficulties affecting health in these countries are the following: malnutrition, infectious diseases, lack of a proper policy for preventive medicine, lack of development for the diagnosis of diseases, lack of vaccines, of medicines, lack of infrastructure of hospitals and other medical facilities for proper patient attention, lack of critical mass of physicians and other necessary health personnel, lack of a long-term, established and lasting policy that allows the keeping of an updated record of epidemiological status (the elaboration of plans), establishing priorities to be solved gradually and constantly training specialized personnel in sufficient quantity and quality to solve health difficulties. A great effort should be made in preventive medicine. Therefore, biotechnology for the development of new diagnostic means and vaccines is very important, in addition to other treatment programmes. AIDS must be mentioned, since more than 95%

of infected persons belong to the Third World. There is a long list of infectious diseases in developing countries in addition to AIDS, for instance malaria, which produces more than 2 million deaths worldwide per year, mainly in developing countries, and dengue haemorrhagic fever. There are no vaccines available yet for these three diseases. Hepatitis B, measles, cholera, tuberculosis, respiratory diseases and diarrhoeal diseases should be mentioned as well. The estimates with regard to HIV/AIDS, comparing the whole world with the example of Africa from the developing world at the end of 1998 (ONUSIDA/OMS, 1999), is given in Table 1.

Table 1. **Estimates with regard to HIV/AIDS, comparing the whole world with the example of Africa**

Situation as of end 1998	Africa (in millions)	World (in millions)
Total persons infected with HIV	34	47.3
Total deaths from AIDS	11.5	13.9
Children infected with HIV	4	4.4
Infant deaths from AIDS	3	3.1
Persons living with HIV	22.5	33.4
New cases of HIV infection in 1998	4	5.8
New cases of HIV-infected children in 1998	0.53	0.59
Deaths from AIDS in 1998	2	2.5

Modern biotechnology has led to a new model concerning the development of vaccines as well as new medicines, such as a DNA vaccine, a vaccine to be eaten in fruit, therapeutic agents and DNA products to combat different diseases, and other improvements. In the developed world there is tremendous scientific development. The speed of scientific achievements is faster day by day. There are scores of recombinant drugs and vaccines produced and sold all over the world by big companies in developed countries (Sasson, 1998). Modern and sophisticated diagnosis of diseases based on biotechnological achievements and many other impacts of biotechnology and of science as a whole are becoming widely extended in developed countries.

There are very few examples of local development in the Third World in medical biotechnology with a great impact on the health of the population. Cuba is one of the most outstanding examples in this matter, with an infant mortality rate of 7.1 per 1 000 in 1998, 99.8% of deliveries being made in hospitals (both figures are the best for developing countries), life expectancy of around 75 years and a complete eradication of malaria and other infectious diseases that produce thousands of new cases and deaths per year in developing countries (FNUAP/UNICEF, 1998). A wide programme in biotechnology has been developed in Cuba (Limonta, 1989) with several institutions having been built, such as the Center for Biological Research (1982), the Center for Genetic Engineering and Biotechnology (1986), the Center for Immunoassay (1987), the Finlay Institute (1989), the Center for Bioproducts (1989), the Center for Genetic Engineering and Biotechnology – Camaguey (1989), the Center for Genetic Engineering and Biotechnology – Sancti Spiritus (1990) and the Center for Molecular Inmunology (1994).

These centres join other scientific institutions built before the 1980s like the National Research Center (1965), the National Center for Animal and Plant Health (1975) and the Institute of Animal Science. Also during the last decade dozens of production plants for the Cuban pharmaceutical industry and the biotechnology industry have been built, accounting for around US$ 1 billion in expenditure on biotechnology in the last 10 to 12 years in this country.

The following is a list of modern biotechnological products developed and produced in Cuba of wide application and sold to more than 35 countries: anti-meningococcic type B vaccine, recombinant anti-hepatitis B vaccine, PPG (hipo cholesterodemic drug), recombinant alpha 2 interferon, recombinant gamma interferon, recombinant streptokinase, recombinant epidermic growth factor, recombinant cattle tick vaccine, recombinant swine colibacilosis vaccine, recombinant erythropoietin, recombinant interleukine 2. There have also been developed dozens of modern diagnostic means for different kinds of diseases based on recombinant antigens or on other modern biotechnological methods; among these are included HIV I, II, hepatitis B, hepatitis C and several others with different presentation formats.

The main challenges to solving the health situation in developing countries are the following:

- to make governments, as well as governmental bodies, aware of the difficulties and work on them;
- to design a long-term ongoing programme of proper scientific development;
- to set aside a larger amount of financial resources for health as a whole;
- a greater commitment and contribution from developed countries and international organizations to health programmes in developing countries.

There are other aspects that can affect scientific activities as a whole in developing countries, such as the regulations about intellectual property.

To sum up, the gap between the developed world and the developing world is growing day by day. There is no general advice applicable to all developing countries. Each one of them should choose its own priorities. Nevertheless, certain ideas should be taken into consideration, such as: a real political will needs to be found in developing countries; local government should allocate more financial support to biotechnology development; more real international cooperation should be developed from the North to the South and also among Southern countries; developing countries should fight to defend their biodiversity and germplasm – it is imperative; the development of a really positive atmosphere in developing countries recognizing the importance of science for creating knowledge and knowledge for creating goods. It is necessary to create appropriate institutions with equipment and a real scientific approach to avoid the 'brain drain' from the South to the North; there is a need to review educational policies in developing countries, starting from primary school. A greater and real participation of the private sector is necessary in biotechnology in the developing world; environmental protection should be a priority in developing countries.

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Science in response to basic human needs, with special reference to water

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Water is necessary for almost every living thing on this planet. Its availability, reliability and quality are fundamental to the environment and to ecology. They are equally fundamental to human health and economic life. We use water in varied ways. We use it for agriculture, drink it, cook and wash with it. We also use it for recreational purposes (e.g. the beauty of lakes, streams and waterfalls). We develop electrical energy from it, sail ships on it and use it to transport waste products, etc. Animals, plants, fishes and birds use it as an essential requirement.

In recent years there has been growing awareness that the amount of good-quality water resources is limited and that we are not coordinating or planning all these multiple uses well. The scale of human consumption and uses of water have been growing dangerously fast, the quality and quantity of the resources that remain are deteriorating. Competition for access to, and control of, the remaining resources has emerged in some places. Criteria and processes for resolving such competition are often defective or absent.

Although water is a very familiar substance, it is also unique. It has no comparable analogies. This is why, in every relevant discipline such as engineering, law or economics, water requires its own special methodologies. It may be worthwhile listing some of these peculiarities:

- Water is not quite the only liquid mineral; but it is the only naturally occurring liquid that is rapidly mobile on and below the Earth's surface, and therefore is variable in both time and place.
- It is enormously abundant; but about 98% of it is not suitable for the most vital human uses because it contaminates itself by dissolving salts, predicted only statistically, not deterministically.

- It is absolutely essential to human life and to all life; but many of our actual uses of it are quite inessential.

This list of water's special features and paradoxes could be extended. They help us to understand why our problem is intrinsically difficult.

The challenge

The challenge that we face now is not, primarily, a technical one. It is political and organizational. There are, however, technical elements in economics, hydrology and engineering that will have to be solved if the main institutional effort is to succeed.

The major challenge is to develop appropriate institutions for effective management, allocation and protection of the water resources of each basin and each aquifer according to the criteria of broadly shared social objectives.

In this sense, the institutions that are required are organizations, but also appropriate laws, appropriate financing mechanisms, appropriate consultative processes. All of these must be made truly effective. They must not be weak constructions, existing on paper only, or easy to circumvent through political influence. Such institutions cannot be inverted and made stable instantly. It will take many years, perhaps a decade or two, to reach the point when they are effective, stable and respected, so the time to start is now.

The hydrological units – river basins, sub-basins, aquifers and sometimes lakes – should be the units of management. Within each hydrological unit's boundaries, resources can be quantified and allocated, and secure systems of water rights can be developed.

Security of water rights can be achieved only if there are effective sanctions against violations of these rights. We are dealing with a finite resource that will become progressively scarcer as demand grows, so attempts at violation of rights (by the state itself, as well as by individuals and groups) must realistically be anticipated. The authority of managing institutions must therefore become sufficiently entrenched to resist such violation.

The dimensions of the water problem

International agencies and professionals are increasingly alarmed about the prospect of a looming global water crisis. Some even say that in the next century wars about water will be more likely than wars about oil. The Food and Agriculture Organization of the United Nations (FAO) made water for life the theme of World Food Day in 1994; the theme of the 1996 HABITAT Conference was 'Water for Thirsty Cities'. In response to these concerns, the Commission on Sustainable Development (CSD) of the United Nations has commissioned a comprehensive assessment of global freshwater resources.

Figures about the number of people suffering from water shortage and about the implications for health and economic growth differ. It is expected that the forthcoming Global Freshwater Assessment will provide a common basis. At this time, it is safe to say that:

- About 1 billion people have no access to safe, fresh water.
- Polluted water is the most important cause of disease, costing about 2 million lives annually and inflicting severe economic and social damage.
- Agriculture is in most countries by far the most important use of water.
- In most developing countries agriculture accounts for about 75% of the water diverted.
- Food security is critically dependent on water. Irrigated agriculture will have to provide the bulk of the additional food required to feed the 2 billion people which the world will have added to the present population over the next two decades.
- Concerns about the loss of biodiversity and environmental degradation have raised awareness among the general public that the environment is a consumer in its own right and should have its own water allocation.

There is a remarkable level of consensus among governments, concerned institutions and the public on the importance of the water issue. A range of concepts is discussed in political meetings and the professional community. Integrated water resource management has become a buzzword. In industrialized countries, the most frequently heard solutions are demand management and reallocation of water among sectors of the economy according to economic principles, in particular the reallocation of water now being used for water-inefficient agriculture.

The global dimension

On a global basis, it is estimated that about 40 000 cubic kilometres of water run off the land every year through the hydrological cycle. Of this, 9 000 cubic kilometres are readily available and could be used by human populations, which corresponds to 1 800 cubic metres per person per year, compared with a current average consumption of 800 cubic metres per person per year. This global figure could lead one to believe that there is still enough water to support a much larger population than the present one. Water availability is, however, a much more complex issue and its assessment requires a more in-depth investigation.

Fresh water on Earth is unevenly distributed. Specific discharge demonstrates the very large regional variation in water resources. It is common practice, when assessing the situation of water resources, to express it as a function of population.

In conclusion, instead of looking only at the seemingly easy solution of reallocating water away from agriculture, FAO advocates a more rational approach based on a thorough analysis of all available options.

Water management options

Water management options falling within FAO's mandate are:

- water policy reviews and reforms;
- increased water-use efficiency in agriculture;
- promotion of sequential water use, reuse of waste water;
- integrated water resource management;
- augmentation of supply.

Thus, in most cases, increasing water use through irrigation is not a luxury but a necessity. Five interrelated lines of action are essential when assisting member countries and their institutions to increase water-use efficiency in irrigation:

- diagnosis of water efficiency problems;
- demand management and economic incentives;
- modernization of irrigation systems, both at field and scheme level;
- improved irrigation scheduling and irrigation management methods;
- training, capacity-building and awareness-creation.

Sequential water use, reuse of waste water

We have said before that there are limitations to the reuse of water in a river basin. However, this does not mean that we are not supporting sequential use of water. In many circumstances, sequential use of water is the most logical and cost-effective principle of water management. It carries the potential for a win-win situation for all sectors, such as:

- increasing water productivity;
- increasing water availability for irrigation;
- making irrigation possible in the absence of any other source of water;
- protecting the environment.

The reuse of farm drainage water is a case of sequential use of water. It is practised in regions where water is scarce. Reuse of drainage water provides a viable option for irrigating a variety of crops and meeting a part of the agricultural water demand.

The range of non-user functions, which could appropriately be assigned to a river-basin authority and which have appeared in our discussions, is quite large. Perhaps it will be useful to assemble the following list of major areas:

- assessment of water resources, in quantity and quality;
- allocation and documentation of water rights;
- management and resolution of water-related disputes;
- supervision of transfers of water rights;
- protection of water resources;
- augmentation of the available or accessible proportion of water resources.

There is plenty in that list to make such an organization professionally challenging and to attract staff of the high calibre that the roles will require.

Conclusion

The exploitation of water all over the world makes one apprehensive for future prospects, especially if one takes into consideration the water shortage which is expected to affect two-thirds of the world's population by 2025. For this reason, governments have started to give water resources a high priority in planning because of their significant role in development.

Water shortage is also the reason behind international conflicts over the building of dams by the countries from which rivers flow. Indeed, international cooperation is required in order to rationalize the use of water by those countries which share the same water resources.

The economic value of water has encouraged some countries to consider it an economic commodity and hence call for pricing it as a means of applying pressure; some vague expressions have also emerged in reports on this topic such as 'transboundary waters' instead of 'joint international waters' or 'joint international water resources'. Some countries which do not have joint water resources have also been included in the agreements relevant to countries which do have joint water resources. All these issues are a cause for grave concern over this important natural resource in which international, human and economic rights have their share.

Such being the case, we insist that science should respond to basic human needs such as water which has a direct effect on man's life. In order to be more practical in directing attention to this resource, we must point out that the forthcoming decades will witness bitter conflicts over water; we accordingly call for:

- giving priority to the social and human dimension of drinking water instead of the economic dimension;
- stressing the fact that the fair and rational use of water is a fundamental factor in drawing up the strategic approach of

managing drinking water; the interest of all countries which have joint water resources should also be taken into account;

- stressing the importance of managing and protecting water resources, contributing to the fight against poverty and reinforcing food security and self-sufficiency;
- emphasizing the close relationship that exists between water quality and quantity, and the urgent need to strengthen international cooperation to support national and regional work plans in the field of environment, water protection and pollution prevention;
- establishing and maintaining effective data networks and monitoring, and reinforcing the exchange of information relevant to the drawing up of policies, plans and work and investment decisions regarding water;
- urging governments to strengthen consultation and cooperation in order to face famine and floods, improve systems of early warning and lessen the impact of disasters;
- stressing the need to pursue research, develop the technology of water management and use in a permanent and sound manner, prevent pollution, improve agriculture, adapt and disseminate new technologies, facilitate the transfer of technology to developing countries, present possible aid to these countries in the field of water resource investment, and conserve the environment.

These terms represent a model for the responsibilities of science and scientists in satisfying human basic needs. In this study, we tried to present a sample of the immediate future dangers and stress at the same time the responsibilities which scientists should shoulder in order to attenuate the effects of these dangers and help man to enjoy a decent life.

The ZERI approach to responding to basic human needs with special reference to poverty alleviation, energy and shelter

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The level of advancement in science today enables all mankind to lead lives of dignity and fulfilment. Yet, more than half of the world's population lives in poverty, lacking essential resources for meeting even basic needs. This presentation shares ideas on ZERI approaches to responding to basic human needs, with special reference to poverty alleviation.

ZERI stands for Zero Emissions Research Initiative, a concept that was initiated by Mr Gunter Pauli at the United Nations University in 1994 and brought to Africa by Professor Keto Mshigeni of the University of Namibia. Through ZERI, a number of zero emission research activities have been initiated, many new ideas have been generated and promising research results have been produced, all of which provide great promise and inspiration for large-scale poverty alleviation, particularly in Africa (Mshigeni, 1997*a*).

ZERI mission and management

ZERI looks at the whole spectrum of materials which people conceive as waste and transforms them to become raw materials for new marketable products. For Africa, ZERI is currently looking at many categories of crop wastes and identifying technologies that could be applied to create new uses for them. ZERI concepts also address issues of global concern, which include challenges posed by: excessive world population; the need for more water; the need for the identification and use of new, renewable and sustainable energy sources; the need for more jobs; etc. To fully benefit from the ideas behind ZERI, the involvement of multidisciplinary teams of experts is needed. We also need partnerships with industry and the use of new technologies which promote sustainable production. We need to sensitize corporate executives who will take advantage of the resulting dramatic increase in productivity, to link up with corporate strategists, and to develop new businesses based on these new concepts. Scientists are also needed to provide a multidisciplinary research agenda and economists must also be involved to help use ZERI as a force in identifying new sectors of the economy. Environmentalists must also be sensitized, in order to promote ZERI as an effective and simple approach for eliminating all categories of waste. Politicians should be involved also, since ZERI offers a new framework for policy-making (Pauli, 1998).

Since the birth of the concept, the International Scientific Advisory Council on ZERI, currently under the chairmanship of Professor Keto E. Mshigeni, who is also the UNESCO/United Nations University (UNU) ZERI Africa Chair, has developed a network of expertise and is increasingly attracting the attention of pragmatic scientists, entrepreneurs, economists, policy-makers and politicians worldwide. Currently, active ZERI nodes have been established in Benin, Brazil, Colombia, Fiji, the Gambia, Germany, Indonesia, Japan, Malawi, Namibia, Nigeria, Sweden, Tanzania, Uganda, UK, Zambia and Zimbabwe, and these are increasingly generating very encouraging results.

To manage this network of experts effectively and to advance the ideals through fast-track implementation, the ZERI Scientific Advisory Council organizes workshops and annual world congresses, and publishes proceedings of these forums. Past workshops and congresses have been supported financially by UNESCO, UNU, the United Nations Development Programme, the United Nations Environment Programme, the Rockefeller Foundation and also by industry. Several workshop and congress proceedings and related publications on zero emissions have been produced. These have effectively contributed to the dissemination of the ZERI concept worldwide. For more information, readers are requested to use this contact address: kmshigeni@unam.na

Selected case studies

Seaweeds: agents for poverty alleviation

Marine waters support a wide array of sea plants. These are often ignored, yet they can be exploited for numerous economic gains. The seaweeds can be used to produce various products, including food supplements. Some of them are very rich in vitamins. In Zanzibar, Tanzania, a research programme on seaweed farming has resulted in a situation whereby 30 000 villagers actively farm the Eucheuma seaweed, whose export income today is almost on a par with that of cloves and tourism, the island's highest foreign-income generators. ZERI intends to assist the Eucheuma seaweed industry by promoting the processing of the seaweed before export, in order to add value to its biomass. In many other maritime countries of Africa, there abound vast quantities of seaweeds of various types, which remain untapped. ZERI catalyses the exploitation of these and related marine resources (Mshigeni, 1997*b*).

The ZERI Tsumeb Brewery in Namibia: a model for industries of the future

The University of Namibia has established a smart partnership with Namibia Breweries, which has resulted in the development of a brewery industrial plant following the ZERI concept. The key inputs into a brewery are grain, water and yeast. For every tonne of beer produced, one uses some 10-30 tonnes of water, which is no longer drinkable when it leaves the factory. It becomes waste. The spent grain after the fermentation of beer is also wasted. Under the ZERI philosophy, these wastes are put to use. The spent water and organic wastes are channelled into a biogas digester to produce renewable energy: methane gas. The effluent from the digester is passed into a series of algal ponds. The algae, which are rich in protein, are used as pig-feed supplement. The oxygenated, purified, mineralized water leaving the algal ponds is conveyed to fish farms. The spent grain is collected, dried and used for cultivating mushrooms and feeding piglets. This way virtually every waste component is put to valuable use. The ZERI brewery activity in Namibia is increasingly becoming an important community education centre on the control of environmental degradation through the generation of alternative sources of energy, thus lessening overdependence on wood fuel. It is also becoming an important centre for learning new technologies, such as mushroom farming, and the construction and maintenance of biogas digesters.

Water hyacinth: an opportunity in disguise

Water hyacinth, *Eichhormia crassipes*, was brought to Africa from Latin America as an ornamental plant by virtue of its beauty. Today the plant is considered as an unwanted, noxious and much-feared weed. In Kenya, Malawi, Uganda, the United Republic of Tanzania, Zambia, Zimbabwe and many other countries in Africa, this weed has aggressively invaded lakes and rivers, seriously blocking boat navigation. It is, in fact, one of the fastest-growing plants; it doubles its weight within one to two weeks. To stop its spread, various methods have been used, including the use of beetles to eat up the plant and toxic herbicides. Both of these are not the best solutions. Using the ZERI concept, this weed can be considered as a resource. It has been used in biogas production; it has been used as a substrate in mushroom cultivation; its fibres can be used in paper production, as an animal feed, for the production of domestic furniture, for water purification and many other uses. Our scientists should serve as catalysts for promoting these and many more uses worldwide.

Bamboo: growing your own house

The Guinness Book of Records (1999) reports that some species of bamboo constitute the fastest-growing plants in the world, growing at an incredible rate of 91 centimetres a day. Many bamboo species form good building materials, which have prolonged durability if appropriately treated. ZERI is undertaking serious research on bamboo and on how it can be used to construct low-cost affordable houses. There is big scope for both South-South and North-South cooperation in the promotion of this vision.

Other intriguing ZERI possibilities

Mushrooms are an overlooked resource in Africa. The volume of the annual world business of mushrooms is US$ 14 billion. Africa's share is a mere 0.3%. ZERI intends to promote commercial mushroom cultivation in Africa, using many categories of organic wastes which occur in great abundance throughout the continent.

Earthworms are extremely beneficial in recycling mineral nutrients in the soil and for promoting soil aeration. But few people in Africa are aware that earthworms can be farmed commercially and can produce a wide range of enzymes for a wide range of industrial applications. The commercial production and exploitation of earthworms is being investigated within the broad framework of ZERI.

Some frog species in Africa, for example the goliath frog and the bull frog, grow to a huge size, and are edible. Virtually none of these is commercially farmed. Equally worth noting is that there is a variety of silkworms and spiders in Africa that produce very good silk. Some of the silk produced runs up to 3 metres. Yet, Africa has to buy imported silk materials at exorbitant prices. Flies can also be put to good use. In Benin, flies have been provided with an infrastructure to produce maggots that are very rich in protein for chicken feed and for other applications.

ZERI is also conducting research on sisal wastes. Sisal industries take only 5% of the total sisal biomass, wasting the rest. Research results from our scientific network show that sisal waste can be used to produce a variety of value-added products, including alcohol, citric acid, medicinal products, mushrooms, etc. Research is also being carried out to produce seed oil for many applications from the plant *Jatropha curcas*. Papyrus is also being studied for commercial utilization in Uganda. ZERI is also investigating the use of other renewable energy sources including solar, wind, and tidal-wave energy sources.

Summary

In sum, ZERI means striving towards: zero waste; zero pollution; complete utilization of raw materials and by-products; creation of new products; generating new innovations; reducing poverty and generating new jobs. Achieving these ideals calls for continuing aggressiveness towards the establishment of new ZERI networks and more partnerships between academia and industry. Our many universities have a key role to play in these endeavours.

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The responsibility of science in the alleviation of poverty in the world

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Poverty has become an obtrusive characteristic of more than 60% of contemporary humankind in ways that have denied these individuals and nations the dignity and freedom that is the innate potential of every human. And this is happening at a time when scientific research in molecular biology and genetics, in astronomy and particle physics, in inorganic chemistry and neurochemistry is breaking across new frontiers of human knowledge undreamed of at the beginning of the second millennium. This is the time also when technological innovations in biotechnology and nanotechnology, in new materials and designer drugs, in cyberspace science and satellite technology have transformed our social perception indelibly and opened up new horizons of wealth unachievable in prior times at the start of the second millennium.

As we begin the third millennium, it behoves science to clothe itself with a conscience – with a responsibility to its creator, the human being – beyond its body of material applications, through technology. In essence, scientific knowledge is required to perform three different functions. First, scientific knowledge provides a kind of regulated truth that gives understanding of the natural universe. Such so-called pure science has 'never answered directly the questions which were put to it'. But searching for this proximate truth has widened the horizons of humankind's knowledge of the physical and biological universe as never before.

The second function of science has come to be the provision of understanding such that informed policy and management decisions can be made. This it has done because of the public trust that science has enjoyed over the greater part of the 20th century. Over the last three decades, however, the public perception of science has become somewhat tarnished, because of at least three constellations of recent events: firstly, the exaggerated claims of scientific 'breakthroughs' that have sometimes been made through the mass media; secondly, the destructive part that science has played in world wars, regional conflicts and the Cold War, as well as in the use of uninformed human beings in experimental medicine without their consent willingly given; and thirdly, the closeness with which science has seemed to embrace the economic and political powers, with the work programme of science oftentimes set by the political agenda, rather than as a joint exercise, thereby obviating the risk of compromising scientific values. There is a decided risk in the ongoing escalating alliances between science and economic powerhouses, which is leading to an increased demand for the marketability of science.

The third function of science is to provide the basis for new technologies. This trend started in earnest early in the 19th century, and the potential to bring about technological innovations through scientific research and technological development (R&D) has greatly accelerated this century. Technological innovations have come to influence the marketplace tremendously, wherever social and public innovations have enabled them to flourish. Scientists have, consequently, become important actors in the marketplace, even though the race for patents has enhanced the feeling of anxiety among the 'purists' in science.

Ethical dimensions of science

The current anxiety comes from the fact that, whereas society requires goods and services in the market, there are also some other, equally vital, goods needed by society – cultural, spiritual and world-views. For four centuries past, science has neglected or divorced itself from the consideration of these latter goods. Science can only divorce itself in this manner if it intends to neglect or abrogate its responsibility towards civil society. What is being sought, then, is the integration of ethics with science – ending the self-imposed isolation from issues relating to ethics, morality and metaphysics which formal science eschewed from the early 17th century.

An eloquent case for such science-ethics reintegration is that recently provided by Kim Rathman (1999) in her article in the journal *Technology in Society*, in discussing justice and equity in the global economy in the context of contemporary international competition in the technology-dominated marketplace. Her basic argument is that, in a global community with interdependent political and economic structures, all people are entitled to participate in the decision-making process. Such decisions must be judged in the light of 'what they do for the poor, what they do to the poor, and what they enable the poor to do for themselves.' In this eventuality, the 'transcendental worth of persons' is validated. Extended to the growing compartmentalization of the peoples and nations of the world into the rich or the super-rich and the poor or the very poor today requires the formulation of national and international structures capable of guaranteeing the minimum conditions of human dignity in the economic sphere for every person. These conditions include the rights to fulfilment of material needs, the protection of fundamental freedoms and the guarantee of participation in the life of society.

The implication of Rathman's expressed paradigm of participation of all people in economic decision-making is profound in contemporary terms in relation to the dominant neo-classical economic theory, which confines the decision-making process in economic relations to that of efficiency of the market. This engineering/utility approach oversimplifies human values and motivation to the single notion of self-interest.

The primary good in economic systems should be seen as the capability and functioning of people. Consequently, the focus of economic policies in national and international development should be that of bringing about capability without insisting on the existence of any minimum floor, so as to take advantage of those essential items available in society. In this way, capability becomes an absolute measure of enhancing one's participation and the quality of life in society.

The capacity being referred to is, in effect, empowerment obtained through possessing science-based technologies such that lives are uplifted. It is this capability that should really be regarded as the basic human need which every person in the world, including the poor, should have the right to possess. Further, this capability must be linked to open access to the sources of such existing technologies and future innovations important to the poor. In this case, then, the poor would have the necessary access to what potentially they can aspire to become.

In considering the place of technological innovation in enhancing economic performance in Africa, particularly in the context of the structural adjustment programmes (SAPs) that have dominated African economic relations since the early 1980s, it can be clearly posited that technological change has now become the main engine of economic growth as well as one which does not automatically accompany capital accumulation. As a consequence, investment decisions depend on the availability of specific skills, relevant know-how and capability, as well as the capacity, to apply these in the required enterprise. The market is not efficient in allocating resources to these three critical factors. For instance, the market cannot, of its own volition, provide the necessary infrastructure that is needed for the successful harnessing of technological assets for long-term economic development, which poverty-alleviation initiatives require. Nor can the market, by itself, generate the required technological capabilities, which presume the existence of an essential mix of skills, because of the specificity of these skills which are not generally found in the general skills which the formal educational system normally provides. Thus, the government (or society) needs to intervene. The essential question is how this intervention should be managed through public policy, so as to assure an optimum growth of these capabilities.

The capability that we are striving for can be broadly described as comprising three principal elements: skills generated by formal education and training; skills acquired from on-the-job training, such as those generated by internship programmes and apprenticeship schemes; and the legacy of inherited skills, attitudes, and abilities that can contribute to industrial development. The new approach to skills development for poverty alleviation, and even poverty elimination itself, can only be speedily acquired if a basic starting point embraces the skills that are indigenous to each community and have, as a result, been culturally validated and time-tested over a long period of time, during which they have also been updated from time to time as new social and economic needs arise.

The way forward for public science

The way forward for science in the 21st century is for the benefits of science to be distributed equally to all peoples and nations, including the poor. The allies of the poor cannot continue to be exclusively those economic and political powers. Science has to be a ‘hand-maiden’ for all people, if it is to begin to salvage its tainted public image. Science has in recent centuries become a willing servant of those in economic or political power – rather than continuing to behave as a true savant of science. The most effective way of science becoming an effective partner of the poor, in uplifting the poor, in uplifting their living conditions and assuring them of their human dignity, is to carefully formulate the questions that the poor are asking in terms that science can indeed answer.

Thematic meeting report

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In his opening remarks, the Director-General of the Islamic Educational, Scientific and Cultural Organization (ISESCO) emphasized the need for sustainable management of ocean resources for energy and food.

The following important points emerged out of the six presentations to the meeting:

- Basic human health needs constitute a major worldwide shameful problem on the threshold of the 21st century in contrast to the dazzling scientific achievements.
- In spite of the spectacular power of modern science, a vast majority of the world population is faced with problems such as food shortages and malnutrition, unsafe drinking water, improper sanitation systems, poor health care, deprivation of shelter, primitive ineffective education. These problems are localized in the least-developed countries in contrast to being nearly unknown in the developed ones.
- There is a need for commitment at the highest level of the developed countries to helping the developing countries.
- Biotechnology applied to health care in developing countries is a special chapter. Biotechnology for the development of new diagnostic means and vaccines is very important.
- It is estimated that, by 2050, 50% of the world population will not have enough water.

- The main aspects of science policy in the next century should be policies for education, dissemination, networking and communication.
- A good education system is the only way to make sure that a nation has the critical mass of educated and trained manpower to build national S&T systems.
- There is a need for research links with the production system aiming at national wealth creation and socio-economic development.
- Networking is an important instrument to implement in international cooperation. Networks are also a most valuable proactive action to create local conditions for scientific research and consequently effectively avoid brain drain from developing countries.
- Science must engage the totality of human aspirations. A platform of ethical responsibility is an essential element of the transformation of science in the 21st century from being solely an instrument of power to one which also engages fundamentally in human welfare issues.
- Poverty alleviation is a prime concern and should provide a challenging new frontier to scientific problem-solving.
- A stronger and sustained political will must be developed among the developing countries to support scientific advances in order to achieve knowledge and with this knowledge to achieve progress.

Discussion

The following points emerged:

- The relationship between research and patents filed as exemplified by Germany was stressed.
- The need to address the issue of brain drain. Brilliant Third World scientists are lost to their countries of origin.
- The need for formal linkages between S&T and development.
- The need to determine the entry points for science in responding to issues such as poverty, illiteracy and diseases, particularly AIDS.

Conference statement

The meeting strongly urges UNESCO and ICSU to take expeditious measures to implement the issues and concerns stated in the *Declaration* and *Framework for Action*. The problems are multidimensional and call for an intersectoral and multidisciplinary approach. UNESCO and ICSU are urged to encourage and actively support the Committee on Science and Technology in Developing Countries (COSTED), the Third World Academy of Sciences (TWAS) and other appropriate bodies to include in their work programmes, scientific studies and actions which address these basic human needs. This meeting recommends that suitable initiatives be established as a Conference Commitment to the 21st Century.

The predictability of climate

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Our climate is a complex dynamical system with variability on scales ranging from the individual cloud to global circulations in the atmosphere and oceans. Climate scientists interact with society through the latter's demands for accurate and detailed environmental forecasts: of weather, of El Niño and its impact on global rainfall patterns, and of man's effect on climate. The complexity of our climate system implies that quantitative predictions can only be made with comprehensive numerical models that encode the relevant laws of dynamics, thermodynamics and chemistry for a multi-constituent, multi-phase fluid. Typically, such models comprise some millions of scalar equations, describing the interaction of circulations on scales ranging from tens of kilometres to tens of thousands of kilometres; from the ocean depth to the upper stratosphere. These equations can only be solved on the world's largest supercomputers.

However, a fundamental question that needs to be addressed, both by producers and users of such forecasts, is the extent to which weather and climate are predictable; after all, much of chaos theory developed from an attempt to demonstrate the limited predictability of atmospheric variations. In practice, estimates of predictability are made from multiple forecasts (so-called ensemble forecasts) of comprehensive climate models. The individual forecasts differ by small perturbations to quantities that are not well known. For example, the predictability of weather is largely determined by uncertainty in a forecast's starting conditions, while the predictability of climate variations is also influenced by uncertainty in representing computationally the equations that govern climate (for example, how to represent clouds in a model that cannot resolve an individual cloud).

Chaos theory implies that all such environmental forecasts must be expressed probabilistically; the laws of physics dictate that society cannot expect arbitrarily accurate weather and climate forecasts. The duty of the climate scientist is to strive to estimate reliable probabilities, not to disseminate forecasts with a precision that cannot be justified scientifically. In practice, the economic value of a reliable probability forecast (produced from an ensemble prediction system) exceeds the value of a single deterministic forecast with uncertain accuracy.

However, producing reliable probability forecasts from ensembles of climate model integrations puts enormous demands on computer resources. As more is understood about the complexity of climate and the need to forecast uncertainty in our predictions of climate, the more the demand for computer power exceeds availability, notwithstanding the unrelenting advance in computer technology. It is possible that, in the future, climate scientists around the world will need to rationalize their resources in much the same way that experimental particle physicists already have.

Modelling of policy-making and policy implementation

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The challenges we face in trying to understand human behaviour or the operation of social systems are no less intriguing than those we face in trying to understand the dynamics of nature (Jervis, 1997). In fact, many would claim that social systems are even more complex. The main argument submitted in support of that claim points to the inherent reflexivity of human behaviour: i.e. the fact that human beings have intellectual capabilities and emotional endowments enabling them to transcend established 'laws' and create new 'reality' in ways that no other species – let alone 'dead matter' – can do. The recognition that human behaviour and, by implication, social systems have important features that distinguish them from natural systems has led to some controversy over what kind of modelling is appropriate and feasible in the social realm. Many argue that the inherent reflexivity of human behaviour makes the kind of modelling commonly used in natural sciences inappropriate and useless; social scientists would be well advised to invest in developing conceptual and interpretative frameworks rather than waste their time on futile efforts to construct numerical and predictive models. My point of departure in this presentation can be summarized as follows: social systems do have important features that are qualitatively different from those found in natural systems. Yet, many of the (methodological) problems encountered in scientific research seem to be sufficiently similar to make a dialogue between natural and social scientists a meaningful and even worthwhile exercise.

The state of the art

It seems fair to say that some aspects of human behaviour are more easily modelled than others. For example, it seems that we have a somewhat better grasp of intellectual operations than of emotional responses. Moreover, we have made more progress in modelling particular kinds of intellectual processes – notably the logic of rational choice – than other activities such as learning or innovation. As long as man can be conceived of as a calculating actor, maximizing some (constant and rather simple) utility function – or, alternatively, as completely ‘pre-programmed’ by social norms and beliefs – we seem to be doing reasonably well. Furthermore, ‘ideal-type’ constructs, such as the perfect market, more easily lend themselves to formal modelling than their impure real-world counterparts. It is abundantly clear, though, that the study of social systems cannot be confined to working with such simplistic and often static notions of agent and structure. In trying to expand their repertoire, however, many social scientists find themselves on the horns of a dilemma between realism and relevance on the one hand and manageability, precision and rigour on the other.

Challenges

Two of the major challenges before us are (i) to develop a better analytic grasp on other aspects or modes of behaviour, and (ii) to improve our understanding of process dynamics. Let me indicate what kind of steps this would involve in my own field of research – the study of policy-making and policy implementation.

Other aspects/modes of behaviour

Policy-making is not merely a matter of choosing between pre-defined options; it is as much a matter of identifying, diagnosing and framing problems, and of searching for solutions or inventing cures. Thus, in the global climate change negotiations, there are multiple conceptions of the nature of ‘the problem’ to be addressed. A natural science conception of climate change is only one piece of input that goes into the political ‘construction’ of the problem. Moreover, policy is almost always made through some kind of collective process. The making of collective decisions is not merely a matter of aggregating preferences; usually it also involves activities such as learning, persuasion and (mutual) adaptation. Social science research has substantially enhanced our understanding of such processes. Yet, we cannot claim to be able to capture them well in the format of formal models. The main reason is, I suspect, that these processes are inherently more indeterminate than processes of calculation and choice. In general, the closer we get to the pole of ‘man-as-artist’, the less capable we seem to be of modelling human behaviour, at least in ‘conventional’ terms. Further research may well also enhance our understanding of the more ‘artistic’ aspects, but if I am right that these kinds of processes are inherently more indeterminate, the gap is not likely to be closed. And at this stage the prospects of an integrated framework for modelling a wide range of human behaviour seem remote indeed.

Process dynamics

This is a wide category, but suffice it here to say a few words about four types of process dynamics that are commonly found in political processes: process-generated stakes, path dependency, momentum and self-invalidating predictions.

Process-generated stakes It is a well-known fact that political processes tend to generate their own stakes for the actors involved. For example, the mere fact that an international conference is taking place tends to create incentives for participants to do well in the eyes of domestic constituencies and important third parties. Moreover, previous ‘moves’ may well have a significant impact upon future incentives. Thus, arguing hard against a particular solution tends to increase the political costs of accepting that solution later in the day. Having yielded to pressure on previous occasions tends to increase the political costs of further concessions (while leading opponents to predict that more will be coming). What these examples have in common is that they refer to potential gains and losses that are generated by the process itself (Underdal, 1992). Such stakes are sometimes important premises for actor behaviour and may well leave a significant imprint on the final outcome. Deadlocks are not always due to incompatible preferences over substantive solutions; the perceived costs of making a particular accommodative move may be the most severe roadblock.

Path dependency Equally well known is the fact that an event at time t_o may constrain the range of options available at subsequent stages ($t_1 – t_n$), or affect their consequences. In politics as in games like chess, opening moves (may) have important implications for what one can do at subsequent stages. Decision theory has developed tools for analysing 'extended games'. Most social processes are subject to a similar kind of dynamics. For example, we know that the distribution of wealth in a society cannot be understood only in terms of present differentials in skills; it has emerged as the accumulated effect of a long sequence of events. In a large system (such as the global economy), this kind of extended sequence can be very complex and therefore hard to trace as well as to model. The social scientist may, though, take some comfort in the fact that this is the kind of challenge that he shares with his natural science colleagues. In natural as well as social systems '…marked divergences between ultimate outcomes may flow from seemingly negligible differences in remote beginnings' (David, 1975).

In social life, we can find other forms of path dependency as well. One of the most important pertains to the evaluation of outcomes. In brief, the value we ascribe to a particular outcome often depends not only on its substantive contents but also on how it was achieved. For example, the same state of affairs tends to be more appreciated if it is achieved through one's superior performance in a hard fight than if it comes merely as some kind of trivial walkover or is brought about through the use of morally abhorrent means.

Momentum In social systems there are multiple self-reinforcing mechanisms at work. One that is of particular importance in policy-making and implementation processes is known as momentum. Momentum is generated when (rapid) convergence on one particular solution or practice generates growing pressure upon remaining parties to follow suit or 'conform'. Momentum plays a role in the establishment and maintenance of a wide range of social practices, from language to fashion. Its impact is, though, not necessarily 'positive'. In some circumstances – notably when there is a premium on defecting from an established practice before others do – even a minor move can set in motion a chain of falling dominoes that can lead to the rapid 'tipping' or collapse of seemingly stable systems (Jervis, 1997, pp. 150 ff.). A wide range of phenomena – from stock market volatility to the collapse of political systems – can be understood only in terms of such self-reinforcing dynamics.

Self-invalidating predictions Conversely, an institution will sometimes survive because the odds are all against it! The reason is that the recognized presence of a serious threat may generate supportive action that otherwise would not have been undertaken. The general mechanism behind this paradox can be described as one of self-invalidating predictions.

Concluding remarks

It seems fair to say that at this point in time we have at least a fair understanding of the general mechanisms at work. However, we cannot yet specify precisely the circumstances in which they are turned on and off, nor their strength in different contexts. These are limitations of a substantive rather than a methodological nature. One promising strategy for making further progress seems to be to work towards a closer integration between 'traditional' social science research and efforts at more explicit modelling. At the very least, such a dialogue can help reveal gaps in current knowledge, facilitate focused criticism and clarify questions for further research.

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Towards an integrative biology and GaiaList 21: new programmes for better understanding of living beings

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It is said that the biosphere makes up only about one part in 10 billion of the Earth's mass. Yet, as a result of evolution for almost 4 billion years, the biosphere presumably consists of hundreds of millions of species, all of which are more or less related phylogenetically as well as ecologically. It is also said that each single adult consists of 60 trillions cells, all of which derived from a single cell, a fertilized egg. Yet all these cells cooperatively keep the integrity of an individual.

Two new programmes are being developed to understand such complexity of living organisms: Towards An

Integrative Biology (TAIB), by the International Union of Biological Sciences, and GaiaList 21, by the Zoological Society of Japan. The TAIB programme emphasizes and enhances the integrative nature of the biological sciences, whereas GaiaList 21 proposes to prepare a list of comprehensive biological information of various living beings present on the Earth and to store their genome DNA, gametes and other cells.

Uncertainty and complexity: a mathematician's point of view

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Uncertainty and randomness are concepts in science more than one century old. They can be traced back to Maxwell, Boltzmann, Poincaré….

One way to formalize uncertainty is the idea of 'sensitivity of a system with respect to initial conditions'. A system here means a transformation in a space of events: from an initial event, the system (process) generates another one, in a unit of time; in some cases, the process is continuous. Such systems are called 'dynamical', discrete or continuous, expressing the idea of successive repetition of the process in a discrete or continuous way: starting at a given point (event) and successively applying the transformation, we generate the positive orbit of that point; similarly, we can consider the past orbit of a given point. Population growth and weather prediction are typical important examples for which dynamical systems have been used as models to try to foresee their future behaviour.

So we want to apply the system many, many times and we would like to describe how it tends to behave in the long run (horizon). Sensitivity with respect to initial conditions is particularly relevant here: the long-term result may vary substantially when we change very little in the initial conditions, that is the initial event. This is clearly the case in the mathematical models for weather prediction, as pointed out by Lorenz in his remarkable work of 1963: 'Future answers vary substantially (degree of uncertainty) with very, very small variation of the initial data. Such a variation is unavoidable, since it is impossible to provide at any initial moment of time the exact values of the temperature, pressure, amount of rain, winds and so on.'

Such systems are called chaotic. The concept became so much in evidence in the last two decades or so that a controversy arose about to whom we should attribute the original idea: to one of those great mathematicians/physicists mentioned before? Or to Steve Smale, a remarkable dynamicist of the 1960s, who led the construction of the so-called hyperbolic theory in dynamics, to be defined later in this presentation? To avoid such a discussion, perhaps we can honour Edgar Allan Poe, who, prior to all of them, wrote the following remarkable paragraph:

'For, in respect to the latter branch of the supposition, it should be considered that the most trifling variation in the facts of the two cases might give to the two important miscalculations, by diverting thoroughly the two courses of events; very much as, in arithmetic, an error which, in its own individuality, may be inappreciable, produces, at length, by dint of multiplication at all points, a result enormously at variance with truth.' (*The Mystery of Marie Rogêt*, Edgar Allan Poe (1809-1849).)

Our present view is that most systems either provide in the future a definite single answer (a possibility that was well appreciated in the 1960s) or else they are chaotic or have multiple answers (much more appreciated nowadays), when we disregard (throw away) a very small number of initial events or, equivalently, a small portion of the space of events. Moreover, the behaviour of such systems on the horizon is concentrated in a finite number of pieces of the space of events (attractors), which can be just simple points (non-chaotic behaviour) or bigger pieces (chaotic behaviour) as above. Our beautiful task is to describe such attractors, whose diameter measures the degree of uncertainty of the model! Such a new present scenario grew from models posed by non-dynamicists in the 1970s, such as Lorenz, Ruelle (and Takens, a dynamicist), Hénon, May, Feigenbaum, Coullet-Tresser, that in a sense had challenged previous models and indeed the very objectives of dynamics.

The concept of a complex system is much more recent and still not very well posed. We want to describe very intricate systems, like the behaviour of neuron-networks (brain), and we know some of the properties that we want to impose to the dynamical systems that could model them, like being non-linear, adaptive, that is, the system constantly changes due to external parameters, having some random characteristics, multiple attractors, fractal structure and so on. Also, a complex system should not be chaotic, but very near being so (on the borderline of chaotic systems).

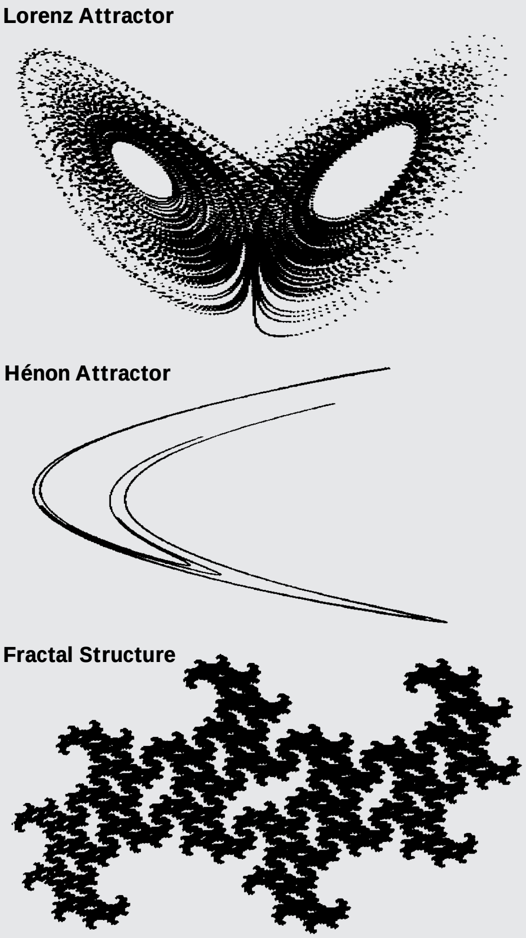
In particular, for a complex system we should not have exponential sensitivity with respect to initial conditions. That is, the long-time behaviour of the dynamical systems that are candidates to model the 'complex phenomenon' should be sensitive to initial conditions, but not so sharply as in the chaotic systems. Also, the local (nearly punctual) structure of the dynamical system should be simple and robust: not much change is seen when we modify the system slightly.

But such a system should display some cycles, that is, global chains of elements, where each one is connected to the next and starting at any element we return to it if we run along the chain. We clarify that an element of the chain is connected to the next if there is a point whose past orbit accumulates in the first element and its future orbit accumulates in the second one. In general, cycles are responsible for sharp changes in the dynamical structure, when we modify the system near them (unfolding of cycles).

Let us now clarify the idea of exponential behaviour of orbits: it means that the distance between two consecutive points in an orbit tends to increase or decrease exponentially (increase and decrease in complementary directions in the space of events). When the exponential behaviour is uniform (or essentially the 'same') for all orbits, then we say that the system is hyperbolic.

In brief, a system is chaotic if the attractors have exponential sensitivity to initial conditions in their basin of attraction. They do not have to be uniformly hyperbolic, as explained above. Important non-uniform examples are the Lorenz and Hénon attractors, together with other examples and ideas like the pursuit of a more probabilistic point of view initiated by the Russian school, which revolutionized the theory of dynamical systems in the last quarter of a century or so.

Figure 1.

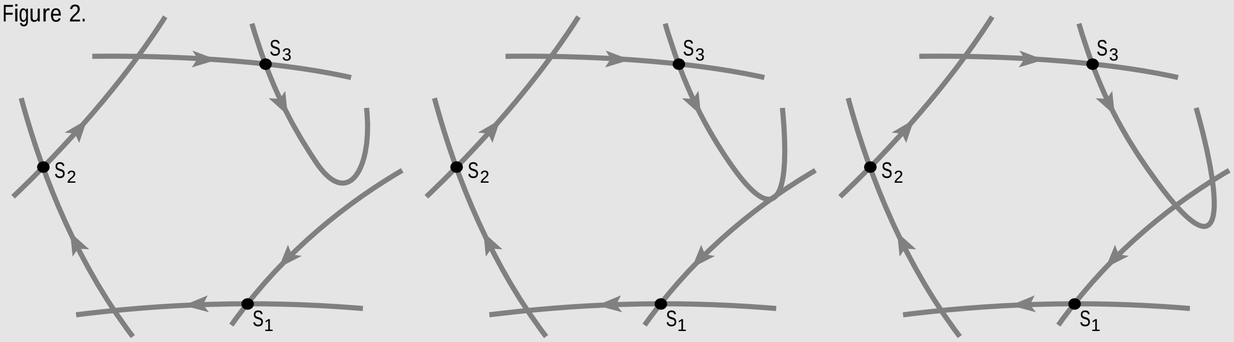


Lorenz Attractor

Hénon Attractor

Fractal Structure

Figure 2.



No cycle

Creating an unstable cycle

A stable cycle

Notice that, in chaotic systems, the attractors cannot be just fixed or periodic points: they have to be more elaborate sets of points, containing at least one-dimensional lines (see Figures 1 and 2). On the other hand, the ideas for complex systems are more intricate and the full definition is not yet established, as commented above.

So, mathematically we are far more advanced in the understanding of chaotic systems (still very much to do, but we can at least propose a possible global scenario) than in the case of complex systems, in the main owing to the lack of really good dynamical models for the examples, like the brain, that we have been considering as complex phenomena. This constitutes a big challenge for scientists, in particular mathematicians.

We shall finish this presentation by discussing a bit further the concept of cycles and their role in dynamics.

First, we observe that in many applications we deal with a 'family' of systems and not a unique one, due to external parameters like, for instance, solar energy in the case of weather prediction, or external sensorial stimuli in the case of the brain.

Then, the creation of cycles becomes unavoidable when we vary external parameters and the systems exhibiting such cycles may be 'transient' ones: they are expected to be on the borderline of the chaotic systems and/or the very simple ones when attractors are just point attractors or periodic ones. Also, we believe that generally cycles should occupy a small part of the space of events: starting in most initial events, in the long run we will end up in an attractor.

Finally, the creation of an unstable cycle and its transition to a stable one definitely make the dynamics become much richer, including new chaotic attractors like the ones named after Hénon and Lorenz.

Acknowledgement I wish to thank Marcelo Viana for discussions on concepts and ideas.

Thematic meeting report

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In nature and society as well as in economic and political life, complex systems play an important part. These systems are adequate to describe the reality; they consider many interactions among many different components. Interactions in the real world are generally non-linear and feedback processes make the systems even more complicated. The definition fits, among other things, the climate, social and biological systems, biogeochemical cycles of different elements disturbed by man, as well as human economics and policy-making. The mathematical treatment of such complex systems needs a special approach. As this conference has demonstrated clearly, important developments have occurred in recent years and natural, social and economic sciences are able now to treat complex systems in an acceptable manner. The general scientific aim in this field is to predict the future state of the system and to give the uncertainty of the prediction. Thus, predictions are not deterministic but probabilistic in nature. The present meeting, held according to a pre-determined schedule, provided an excellent opportunity for well-known scientists from different backgrounds to discuss complex systems in some detail.

As in the case of other complex systems, weather and climate are controlled by two types of forcing: by ordered and chaotic behaviour. Complicated interactions can undergo spontaneous self-organization, producing order in chaos. On the other hand, the system is sensitive to small differences: slight changes in initial conditions can result in a different response. This leads to variations from order to randomness. The result is an oscillation between a number of quasi-stationary states. Meteorological/climatological predictions concern changes in weather conditions, seasonal and long-term (10-100 years) variations. An essential aim presently is to give the uncertainty of forecasting. The estimation of the uncertainty can be carried out by running the models several times by using an ensemble of initial states. As expected, the dispersion of values foreseen increases with time. This can be demonstrated by different examples: by predicting the temperature in London, the trajectory of hurricanes or the worldwide distribution of rainfall modified by El Niño events. It is an interesting fact that in this last case the uncertainty of the forecasting also has a spatial distribution. One of the most important problems of climate models is the consideration of processes taking part on sub-grid scales, like cloud formation. In spite of the difficulties, including the ocean-atmosphere interactions, the validation of complex models describing the atmosphere gives encouraging results.

The study of changes in the underlying climate attractor as a function of the increase in atmospheric greenhouse gases is an essential part of modelling. Thus, the investigation of the biogeochemical cycles of relevant substances is of great interest. In this respect the carbon cycle disturbed by human activities is of particular importance. The increase in the concentration of carbon dioxide in the atmosphere is demonstrated well by data recorded at Maona Loa Observatory (Hawaii, USA) as well as at the South Pole. However, the data are different at the two measuring sites. Concentrations observed at the South Pole show practically no seasonal changes, whereas, at Maona Loa, important annual variations are measured owing to the effects of vegetation. It is to be mentioned that the amplitude of annual cycles has increased during the last year indicating a more active vegetation cover. Nearly one-third of anthropogenic emissions are presently caused by deforestation in tropical regions. However, in future, fossil-fuel-burning will be the overwhelming man-made source. In spite of efforts in recent years, the carbon cycle based on our present knowledge is not closed: sinks do not balance atmospheric sources. This means that further research is needed in this important and interesting field.

The social world competes well with the natural world in terms of complexity. One distinctive feature is the inherent reflexivity of human behaviour. The intellectual and emotional capabilities of human beings introduce strong indeterminate elements, raising important questions about the approximation and feasibility of numerical predictive models. What can be modelled in such terms at present are primarily certain aspects of the behaviour, notably decision-making, more precisely rational choice, and ideal-type constructs, such as the perfect market. We have severe problems with other aspects, including search, perception, learning and process dynamics, such as process-generated states, path dependencies and momentum. The main difficulty pertains to substantive theory rather than to methodological tools. A further question is whether we can construct a model enabling us to determine, among other things, the political feasibility of a certain action. Such kind of modelling has to describe options for policy-makers to help their decision-making.

As a result of evolution during almost 4 billion years, the biosphere consists of a great number of species. It is estimated that possibly 100 million species live presently on planet Earth: the biosphere really is a complex system. At the same time, the body of a certain species has also complicated enormously. Thus, each human adult is composed of 6 x 1 013 cells which act in concert to maintain the integrity of individuals. The surface of our lung is around 100 square metres, the length of our blood vessels is 100 000 kilometres and we synthesize 1 014 molecules each second, to mention just some examples. This illustrates clearly that a human being is a very complicated organism. For a better understanding of such complex living systems, well-organized international programmes are needed, like the Program Towards an Integrative Biology of the International Union of Biological Sciences (IUBS). The Zoological Society of Japan has also launched a project called GaiaList 21 to gather comprehensive information about all living species and to know better the beautiful tapestry of living organisms. One can conclude that the study of biocomplexity is obviously necessary to understand not only the living world as a whole, but also human beings: ourselves.

From a mathematical point of view, the study of complex systems is relatively recent and still not very well settled. This means that modelling in this field is a challenge for the community of mathematicians. While the simulation of chaos (e.g. exponential systems) is rather advanced, more efforts are needed to describe complex systems in a more suitable way. The general peculiarities of these systems are that they do not provide unique, deterministic solutions, but they give multiple, probabilistic answers. They make strong claims about the universal behaviour of complexity. Such probabilistic predictions, together with their uncertainties, are more useful in many cases than deterministic ones. The future state of variables of a system with non-linear relationships is not given in the phase space by one point, but by strange abstract patterns called attractors. The form of natural objects like clouds and landscapes can be characterized by fractals with invariable complexity.

The lectures during the thematic meeting were followed by a lively discussion. Besides special questions and remarks concerning different topics presented, from climate to social science, there was general agreement that the study of complex systems has brought science closer to the real world. The usefulness of such studies in biology, social sciences and policy-making was emphasized in particular. It was stated, among other things, that we have to consider chaotic theory with satisfaction, since natural and social systems behave in such a way. There are no unique solutions but probabilities: the world is predictable, but with a given uncertainty. The participants in the meeting also agreed that it would be meaningful to make changes in our education system to teach future generations that the world is composed of complex systems which cannot be simulated in the usual deterministic way. Finally, it was concluded that, although during the last decade important progress has taken place in the scientific approach to complex systems, this important field will be a challenge for scientists of different disciplines for a number of years to come.

Scientific cooperation in Latin America

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The development of sciences in Latin America is extremely uneven both in disciplines and geographical distribution.

There are some institutions and laboratories of high international standards but the ratio of scientists per total population is much lower than that of the most advanced countries and the investment in research is on average below 0.4% of gross national product (GNP).

Therefore, to tackle problems of high significance for Latin America, and to help the least advanced sector, it is indispensable, on the one hand, to increase investment in research and development (R&D) and, on the other, to improve cooperation within the region and abroad.

Several national, multinational and regional scientific institutions and networks are working to foster endogenous and worldwide collaboration. Among them, governmental agencies for science and technology, bilateral and multilateral agreements, the Organization of American States (OAS), Ibero-American Programme of Science and Technology for Development (CYTED), INCO, etc., should be mentioned.

Several regional networks covering basic sciences have been created along the years with the support of UNESCO and ICSU, namely: Latin American Network of Astronomy (REDLA), Latin American Network of Biological Sciences (RELAB), Latin American Physics Network (RELAFI), Latin American Mathematics Network (RELAMA), Latin American Chemistry Network (RELACQ), Latin American Network of Earth Sciences (RELACT). These are very active in promoting postgraduate training, regional research projects and studies of specific problems relevant to the region.

Each network constitutes a non-governmental organization, which is highly representative because it integrates the efforts of very distinguished scientists, regional scientific societies and institutions, and in some case members of the governments.

These networks have constituted a Coordinating Committee to stimulate the generation of local and regional policies and mechanisms for the promotion and use of basic sciences as tools for development and integration.

UNESCO, OAS and several governments have already recognized the efficiency and effectiveness of these networks for executing substantive actions and have provided resources to conduct those activities.

At the moment, comprehensive projects are being drafted to be submitted to potential donors to be able to further increase their working capacity in three major areas: the enhancement of the relationship between science and society (including the productive sector), the improvement of understanding between science and governments and the development of each particular field of science.

The first two points are crucial because political decisions to provide more resources for science will only come as a consequence of a better appraisal by governments and society at large of the benefits that science can render.

Science across borders: how far to the goals? A point of view from a developing country

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Science and technology (S&T) should know no borders. Progress in S&T benefits all of humankind. Development of science in each country relies upon the nation's own efforts and is also affected by international exchanges and cooperation. Evidently, international scientific cooperation is an important component of the social commitment of science.

Science across borders required in a globalizing world to solve common issues before humankind

In the world today, the highly developed economy demands resource management worldwide, and the advancement of transportation and communication, especially the growth of the Internet, have provided powerful means unseen before for exchange and dialogue among nations and regions. Mutual influence and interdependence among different countries are deepening; the global economy is shaping up.

Nevertheless, the impact of the global economy and technological advances on different regions and nations differs essentially. The Internet is raising the efficiency of economic operations in developed areas to a level that has not been known in history. High-tech industry, centred on, and driven by, information technology, has brought to countries of the Organisation for Economic Co-operation and Development (OECD) continuous economic prosperity for more than 10 years. At the same time, it is widening enormously the gap between the developed and underdeveloped areas. A developing country might fall further behind the world. So, in discussing the formation of the 'Earth-Ball Village', it should not be forgotten that about three-quarters of the world population is threatened with such pressure and crisis.

A pressing issue in the 21st century is the rapid increase in the world population. The world population at the beginning of the 20th century was 1.6 billion; now it is about 6 billion, a fourfold increase. It is expected to grow to 9.5 billion by 2050, among whom 8 billion will live in developing areas. As a result of many factors, the territory suitable for human existence is shrinking constantly. The world, especially the developing world, is becoming seriously overloaded. Furthermore, the areas that have been behind during the long past period are of course trying with all their might and enthusiasm to accelerate economic development and raise domestic living standards. They are bold and assured to do so and the international community has every reason to support them in doing so. But, as a side-effect, it implies serious danger. Some 20% of the world population living in highly developed areas accounts for nearly 86% of world consumption, while the other 20% living in the most underdeveloped areas accounts for only 1.3% of consumption worldwide. If a considerable part of the three-quarters of the world population living in developing countries succeeded in raising their standard of living (per capita consumption of energy, fresh water and all critical resources) to nearly the same as in the developed countries, it is almost certain that the natural resources of the whole world would be exhausted and its ecology and environment would deteriorate further.

To explore essentially innovative solutions for resource saving, environmentally and ecologically sustainable socio-economic development, mainly with the help of S&T, is a vital challenge and urgent subject for the 21st century for all nations. This is the target of science across borders in the new millennium.

Progress in science across borders and the challenge of the new century

In the past 20 years, because of a comparative openness in technology transfer and cooperation, about half of the technologies introduced from abroad into China have come from Europe. China and the European Union have signed an Agreement on Science and Technology Collaboration, and developed effective collaboration in many important fields. The Science and Technology Collaboration Agreement between the governments of China and the USA includes more than 30 additional protocols between departments of both sides concerning many important fields. S&T collaboration projects between China and Japan are increasing too. On the threshold of the new century, China expects more extensive international collaborative projects in science and high technology.

Regional S&T cooperation and collaboration are developing too. In 1996, at the informal meeting of Asia-Pacific Economic Cooperation (APEC) leaders, President Jiang Ze Min initiated the setting up of the Asian-Pacific Industrial-Technology Park Network and selected four sites in China for opening to all APEC member countries. In November 1998, to facilitate regional economic and technological cooperation, Jiang proclaimed he was setting up a US$ 10 million China-APEC Industry-Technology Cooperation Fund.

China's reform and open-door policy since 1978 has resulted in an unprecedented development in international scientific exchange and cooperation. In 1997, China conducted 35 000 projects in international S&T collaboration, 25 times the number in 1978, 120 000 person-times in exchange of scientists, 16 times that in 1978. In 20 years, more than 700 000 foreign specialists have been invited and 300 000 person-times have been sent abroad for training.

Although big progress has been achieved in the past in international S&T cooperation, there are still obstacles to be overcome; furthermore, new challenges and opportunities of the new century are emerging on the horizon.

- Owing to the revolutionary advancement in S&T, brand-new opportunities and challenges are emerging before our eyes. However, the ability of the developed and developing countries to respond to these differs greatly. In most cases, the advanced countries take more opportunities and underdeveloped countries take more risks. The consequences of all degradation are borne disproportionately by disadvantaged groups.
- It used to happen in scientific research collaboration between developed and developing countries that scientists from developed countries would play a dominant

role in specifying research topics because of their privileged position in advantageous technology and financial support ability. To scientists from developed countries, the paramount consideration is either the frontier of purely scientific exploration or the topics that interest their government. To the developing country, however, it is the more down-to-earth problems that need to be addressed first. Often the wishes of the developed country prevail. Research topics raised in the context of the needs of developing countries in many cases have difficulty in finding opportunities for international collaboration.

- The ‘brain drain’ issue. A great number of well-educated and talented youngsters go across borders from developing to developed areas, making essential contributions to S&T. The expenditure on their education is actually contributing financial support to science across borders by people of the developing countries, which has never been recognized by anybody. In many cases of international scientific collaboration, financial support from developed countries cannot be used outside country borders. This practice is considered normal and reasonable. The fact that financial support from developing countries is flowing to developed areas together with the human power flow used to be considered normal and reasonable too. But in all these facts, aren’t there any very unreasonable and unfair points?
- Discrimination against scientists from countries of different socio-political systems still exists as a serious barrier to international scientific exchange and cooperation. For a long time, scientific communities of many countries and many international scientific organizations like ICSU and ICSU members have made big, effective efforts to overcome this barrier and realize the universality of science and free international scientific exchange. Unfortunately, unsatisfactory events still happen from time to time, showing undisguised discrimination.

Expectations of WCS: a new promise of science addressing global issues for human development in the new century

The Conference is anticipated to have a long-lasting impact on the global scientific community, especially with regard to international scientific cooperation and exchange. In the main document of such a global event on the eve of a new millennium, perhaps ‘science across borders’ should be seen as one of the most important and influential points for achieving the goal of building global science in a globalizing world. It is suggested that:

- Science across borders contributes to narrowing the gap between the South and the North:
  - it advocates a constant increase in budget by the advanced countries for international cooperation in the same proportion as their domestic R&D investments;
  - it supports international scientific cooperation programmes which give priority to the needs of developing countries;
  - it encourages and takes measures for effective support to scientists in developing areas in accessing scientific documents via the Internet (a good example is the National Academy of Sciences in the USA, which provides free access to all NAS publications via the Internet);
  - it initiates, supports and encourages young people from developing countries who have studied abroad to contribute to their homeland.
- Science across borders contributes to the elevation of public understanding and recognition of science. This is particularly important for underdeveloped countries where superstition, pseudo-science, ignorance and backwardness are still rampant and should be replaced by rational cognizance of science.
- Science across borders develops a commonly recognized norm of ethics in science and advocates that state sovereignty, territorial integrity, equally respected human rights (against double standards in human rights), freedom of all people in selection of political systems, religions and lifestyles should be respected. Science that serves superpower politics is immoral science, is against the ethics of science and should be condemned by the scientific communities of the whole world.

In taking up the challenge of the new century, the Chinese scientific community wishes to work hand in hand with our international counterparts and strive to make our due contribution to world peace and the advancement of S&T.

International collaboration in science: lessons from CERN

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General remarks about international collaboration

We all agree that science is international and that it is facilitated by drawing on the deepest sources of knowledge wherever they may be available. On the other hand, national policies for science and technology increasingly emphasize strengthening national economies and gaining market advantage. In the UK, for example, the last government White Paper on science policy states explicitly that one of the goals should be to strengthen the national economy. This could have a negative effect on international collaboration and it could lead to increased emphasis on support for applied research and development, which is designed to increase competitiveness in the short run. This in turn could lead to a decrease in support for basic science – 'blue skies' research – which has long-term goals and produces what economists call 'public goods' that are good for the economy but not for individual enterprises. These policies could also foster the idea that fundamental research can be left to other countries.

In these circumstances it is particularly important to analyse the advantages and disadvantages of international collaboration – when it is appropriate, when it is not appropriate and what forms it should take (for a fuller discussion, see Llewellyn-Smith, 1999).

There is a very wide spectrum of activities in science and technology, ranging from basic research, motivated by curiosity, to commercialization of technology. The connection between these activities is highly non-linear. Nevertheless, it is generally true that in the case of curiosity-motivated research and research focused on generic development of technologies, it is usually very difficult to predict when, where and to whom the benefits may flow. Furthermore those benefits may be very, very long term. Industry generally does not want to invest in this sort of research, so it is the responsibility of government. For the same reason, there is no great national advantage in supporting research at this end of the spectrum – it is good for all of us – so this is a particularly good area for international collaboration.

Government funding is, of course, also essential for research related to non-commercial topics, which is not for profit, for example on the environment, diet or transport policy. International collaboration is also natural and appropriate in such areas.

The positive reasons to collaborate are fairly obvious. First, progress is fastest and most cost-effective when it draws upon knowledge wherever it may be found. In addition, our experience at the European Laboratory for Particle Physics (CERN) shows that when you put together scientists and engineers who have been trained in different traditions and look at problems from different points of view, often the whole is better than the sum of the parts and they come up with original ideas for solving problems. Second, many areas of research require broad interdisciplinary approaches and international collaboration may be essential in order to reach the necessary critical mass. Third, there are some activities, such as particle physics – to which I will return – and space research, that are beyond the means of most – in fact probably all – individual countries, so that if we want to do this research we must collaborate. Furthermore, even if an activity is affordable nationally, international collaboration may be desirable in order to reduce costs and avoid duplication.

Finally collaboration has a valuable human and political role in bringing people together, which it is appropriate to emphasize at this Conference. CERN, for example, collaborated with colleagues in Eastern Europe and in Russia during the period of the Cold War, keeping open channels of communication and developing valuable personal links – not just between the old grey-hairs but also between young students.

International collaboration can take many different forms, ranging from the creation of joint institutes to joint ventures, sharing of results and data, and setting up informal networks. We have to try to understand the circumstances in which different forms of collaboration are appropriate. In my opinion, formal collaboration should only be established if it is essential for financial reasons, or if there are clear advantages for the scientists involved. I am very much against top-down organization of collaboration.

I also think that one has to be careful about purely financial arguments for reducing duplication. Science thrives on competition. I get worried when people talk about coordinating science policies in Europe. If we had one policy and it was wrong, we would be in trouble. Science thrives on having different sources of funding. Multiplicity of sources is one of the strengths of the USA, where there is consequently a greater chance that some policies and choices will be right. We also have to avoid over-planning on a world scale, or we may all go off in the wrong direction and miss new ideas.

Lessons from CERN

I take particle physics as an example of ‘big science’ – science that needs big facilities. First a parenthesis: because these facilities are usually very expensive, there are very few of them. Therefore, when you evaluate the cost per participant properly, big science is generally not as much more expensive than most other sciences as many people think.

Particle physics is the study of the constituents of the matter and the forces that determine their behaviour at the most basic level possible. It asks a deep question: why does the universe and all the matter in the universe have the form it does? The primary tools of particle physics are big accelerators, with which we accelerate particles to the highest energy the taxpayer will allow then smash them together in order (crudely) to break them up and try to find out what they are made of. We surround the collision regions by giant detectors in order to analyse what goes on in the collisions. These big detectors are nowadays themselves huge projects costing hundreds of millions of dollars that generally have to be built by large international collaborations.

Traditionally, building and operating the accelerators, and building the detectors, have been funded in different ways. The host nation or the host region – Europe in the case of CERN – has funded the construction of the accelerators and paid the running costs. Nevertheless, the door has been kept open to any scientist from any nation wanting to contribute to the detectors and join the experiments. There has not been any admission fee or any charge for the capital or running costs of the accelerators. This tradition has been followed in high-energy physics throughout the world, at CERN and by our friends at the High Energy Accelerator Research Organization (KEK) in Japan, in China, Russia and the USA. This open-door policy has stimulated collaboration and contributed greatly to progress in particle physics.

Construction of the detectors is dispersed among the collaborations, so that parts of the detectors that are needed for CERN’s next project in Geneva are being built in Tokyo, Beijing, Chicago, Madrid – all over the world, close to the students and close to local industries so that they benefit from being involved in the technologies. The parts will then be brought together and assembled at CERN.

CERN today has 20 Member States – most of the Western European countries plus five countries from Central and Eastern Europe. But the scientists involved in the experiments come from all over the northern part of the globe and parts of the Southern Hemisphere – 8 000 scientists altogether of some 80 different nationalities, based in 52 different countries. The largest number (4 700) come from Europe, with the rest from all over, including particularly large numbers from the USA and Russia, and some from developing countries, such as Pakistan for example.

I should emphasize that CERN discourages ‘brain drain’. Participants remain based in China, India, Pakistan, etc., but, because the door is open, they can visit CERN and participate at a world level in very exciting science. They come and go, taking back knowledge of new technologies and ideas. The next point is that, of the 8 000 users, maybe something like 3 000 are graduate students. Many later move out of science into other areas, taking with them the valuable experience that they have gained working at CERN and a network of useful contacts.

A third point is that, because collaboration at CERN involves so many different countries, there is a need for excellent communication. That is why it was at CERN, more or less exactly 10 years ago, that the World Wide Web was invented. The Internet – the physical wires – existed. But in order to work together building the big detectors, CERN needed a way of linking computers and exchanging information without having a PhD in informatics and this led to the Web.

CERN works and the open-door policy allows scientists from anywhere in the world to participate. I would certainly not argue that scientists from the developing or underdeveloped countries should participate in a major way in this field. But it is good that some people can and do come from a very wide range of countries to join in the quest for the origins of matter and of the universe.

In the last two decades the decrease in the number of accelerators worldwide, as they have become bigger and more expensive, has led to much larger cross-use of facilities by people from different regions. This has made it harder to convince finance ministers that we should maintain the open-door policy and there has been pressure to charge users coming from different regions. At the same time, as the cost of the facilities has gone up, they have reached the limit of affordability for individual countries or even individual regions. Consequently, there has been pressure to extend the collaborations to cover building as well as exploiting the accelerators.

There have been two major attempts to create worldwide collaborations for building accelerators, one at the Superconducting Super Collider (SSC) in the USA, which failed, and the other for the Large Hadron Collider (LHC) project at CERN, which built on earlier European experience at DESY in Hamburg. It is interesting to ask what lessons can be learned from this experience.

First, it is interesting to ask why CERN has worked at all, given that it is not so easy to operate an organization with a budget provided by 20 different countries. One of the reasons it works is that it has to work, because it is central to the research of the participants. In Europe, before the days of the jumbo jet and easy transatlantic travel at least, if we wanted to work in this field, CERN provided almost the only world-class opportunity. There was, therefore, overwhelming bottom-up motivation for the scientists to make it work. Second, there is no dominant partner. At CERN, the four big countries, Germany, France, Italy and the UK, are similar in size so there is a balance of views, which can easily be influenced by the smaller countries if the big countries disagree. Third, it has worked because the governments have taken a rather hands-off approach and let us scientists get on with it.

Furthermore, CERN was built on a green-field site in one of the smaller participating nations, namely Switzerland, and that again has allowed everybody to participate on an equal basis. It is an intergovernmental organization based on a treaty and this has provided stability for the organization, which has been important for its success. These special features of CERN are unlikely to be repeated. Moreover, the mode of globalization of the LHC project at CERN (which has brought Canada, India, Israel, Japan, Russia and the USA into the construction of the accelerator) depended strongly on prevailing conditions.

New projects in particle physics or other fields will start on the basis of different conditions. Nevertheless, I think there are some general lessons that we can learn from CERN's experience.

First, although it is nice to start international collaborations on green-field sites – so that everybody comes in on an equal basis – we have learned from the LHC/SSC experience that there are advantages in using an existing laboratory, incorporating the existing infrastructure and, even more important, using existing human resources. It is hard to set up big laboratories and make them work, and there are big advantages in basing new projects in existing centres of excellence with the necessary expertise. It certainly makes it easier for others to come in if the host nation or region contributes existing facilities and agrees to bear the long-term consequences at the end of the project.

Second, collaborations work best when they are driven bottom-up by the scientists involved. In the case of the LHC, it was the pressure that physicists in the USA, India, Japan, etc., put on their governments that persuaded them to contribute to the project.

Third, contributions should be negotiated as early as possible in a project in order to involve everybody as real partners having a say in the design and orientation. Deciding to do something in one country or region then inviting people in afterwards is not likely to work. In fact the LHC was approved before countries from other regions joined, but we were able to offer added value to new participants. We had the project approved on a two-stage basis and were then able to say to countries in the rest of the world: if you come in, your contribution will speed up and improve the project. It is essential either to involve people before project approval or to offer them added value if they come in later, at least if an open-door policy is adopted.

Fourth, to make a real partnership, the host region or country should offer others a proper voice in policy decisions, possibly out of proportion to their financial contributions, even if this seems rather generous to finance ministries. This is important in order to get a real collaboration and it is not unreasonable if we think that, over a long period, the cross-use of different projects in different fields in different regions of the world will balance out.

In considering reciprocal scientific collaboration, it is an illusion to seek what is sometimes called 'detailed balance'. When we were trying to negotiate a deal with the USA for the LHC, there were some people there who did not wish to contribute unless Europe promised to contribute later to an accelerator project in North America. That would not have worked. Such projects are too few in number and the periods between them are too long. Attempts to balance everything and count every penny may appeal to accountants, but they are bad for science. It is necessary to be generous and seek collaboration in the belief and hope that it will open the way to reciprocal contributions that could be in some other field in the future.

Many people have talked about something called the 'basket approach' to collaboration in big science. The idea is to make all the big players happy by approving big projects in several fields (e.g. accelerators, space science and fusion) at the same time. Then one could be in Asia, one in Europe and one in North America. That is not going to work either. There are not enough projects and some would have to be approved on an artificial time-scale. The only way forward is project-by-project on the basis of faith that contributions will balance out across all fields in the long run.

Fifth, as far as possible, the construction of components in big-science projects should be distributed among participating nations in order to maximize involvement. This is not easy. When I was negotiating contributions to the LHC at CERN, the European governments said 'We're paying the major costs, including salaries, so the rest of the world should contribute cash, not components. It's unfair if we pay to dig a hole in the ground then let the Japanese and Americans contribute high-tech components to put in it'. But of course the other governments said 'why should we give you cash; what's in it for us?' So we had to reach some compromise. Distributing construction of components is important not only in order for governments to see that their industries are involved, but also so that the participating laboratories and scientists have, and feel that they have, a real role. This again requires understanding and generosity on the part of the host region or country.

Finally, there are many barriers to collaboration. In Europe, for example, we have developed a way of working essentially by consensus. In contrast, our colleagues in North America tend to take decisions by what they call a 'shoot-out'. Bridging such culture gaps is difficult. Reconciling different accounting systems and different bureaucracies is also difficult and takes time.

The CERN experience has been a very good one. It has clearly demonstrated the scientific and human benefits of collaboration. I hope that future experience with the LHC will be equally successful and in particular that CERN will be able to keep open the door to scientists from all countries who want to come and work there. The LHC project is the first mega-science project constructed by a global partnership driven bottom-up by the wishes of the scientists involved. It is going to be very interesting to see how it develops. I do not want to put it forward as a necessarily preferred blueprint for future projects, which will arise in their own particular circumstances. I believe nevertheless that certain lessons can be drawn from the CERN/LHC experience and that they could be useful for others wanting to set up global projects.

Reference

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Scientific international cooperation – an imperative

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The world's industrialized countries already live in a knowledge-based economy. One result of this is that their governments increasingly look to science and technology as a means of increasing national economic wealth. This, in turn, has led them to exert greater control on science and technology budgets. Governments have also realized that science creates know-how and that know-how gives way to power. Therefore, governments are seeking control over their national science systems and the use of scientific results. This has led to demands for accountability that have put science and technology managers under pressure – a pressure that is transmitted to scientists themselves, who have already been made aware of the need to achieve results that are visible to citizens.

One possible victim of this situation is fundamental research, which finds it difficult to demonstrate the usability of its results in the short term. It is fair to say here, however, that governments, even if they do not fully understand and support academic freedom, often recognize that interference in the action of basic research may be potentially damaging. A second victim is international cooperation, practically for the same reason in that it often deals with fundamental research – apart from the fact that it is in hidden parts of national budgets and represents a succulent objective in times of restrictions.

International scientific cooperation can be divided into two groups: bilateral and multilateral. These two groups can in turn be subdivided into spontaneous collaboration (scientist to scientist or laboratory to laboratory), inter-institutional, and intergovernmental or formal top-down agreements (the European Laboratory for Particle Physics (CERN) is a well-known example). It appears as if, in general, transnational projects, once very popular, are now either in decline or, to say the least, have to deal with practically frozen budgets. In Europe, for instance, no comparison can now be made with the 1960s and 1970s when many initiatives were launched. Certainly, there may be good reasons for this state of affairs. However, I would like to argue that there are at least equally good reasons to promote and stimulate international scientific cooperation. Although I am taking a view from Europe, I suggest that similar arguments can be applied elsewhere in the world with due care, especially taking into account local conditions.

Globalization of the economy has already taken place and there are no indications that this is a reversible process. It is equally evident that globalization is being legally backed by institutions such as the World Trade Organization (WTO), which is the guardian of liberalization and trade. To cope with and benefit from globalization, industry is reorganizing its structures, making alliances and undertaking mergers to increase competitivity and benefits.

Globalization is nothing new to scientists who, throughout history, have been open to the international exchange of knowledge. However, now that industry has undergone a significant change due to globalization, it looks as if science managers and scientists, at least those in the public domain, are currently looking at the phenomenon as if they were not concerned by it.

How can science respond to globalization? I do not have an answer to that question. But it seems that action rather than stagnation is required in the field of international cooperation. Increased international cooperation in scientific research seems to me the right recipe for coping with continuous change, an impressively increasing number of discoveries in all fields of science and a rather astonished society that cannot assimilate the speed of change. Curiously, globalization has increased economic competitiveness but seems to have encouraged anxious, inward-looking societies with the resulting desire to control things by keeping them at home.

Arguing for a more marked activity in scientific international activities based on the fact that science has no national boundaries is as simple as it is right. However, there are more reasons than this to support it. One of them is the incremental nature of scientific knowledge. Even radical discoveries are based on incremental knowledge. Privileged minds often respond to previous knowledge just by looking at it in a different way. Interchange of scientific ideas is an old matter, so well represented in Europe by the Republic of Letters[1]. In addition, it is a fact that international competition and cooperation raises standards and promotes excellence. However, increased short-termism works against international projects because they tend to be long and often relatively open ended. Naturally, obstacles to international scientific cooperation often stem from national pride or, to be more precise, national budgets. No government likes to see its own money used for the glory and benefit of other nations. This is in opposition to the international nature of science, whose grassroots need international validation of their work through peer review. I do not find any reason to defend distinctive scientific cultures between nations, although national specialities and traditions can be identified. One can add that intellectual property rights management (let alone bureaucracy), accountability and confidentiality (in particular in defence projects) are also well-known difficulties for international collaboration.

Science has evolved in such a way that the use of large research facilities for certain fields of experimentation has become indispensable. This calls for international collaboration in sharing facilities and investments to make an efficient use of funds, if not as the only way to afford certain facilities (e.g. CERN). In addition, a critical mass is generally necessary to develop excellence and to break new ground, which again calls for unity of research groups regardless of nationality.

The increasing use of information and communication technologies is nothing but an excellent instrument invented by scientists for better exchange of experiences and knowledge. Information technologies in international collaboration allow for inter-comparability of data to an extent that has not been possible up to now. It is not difficult to appreciate the benefit of having access to new data and its inter-comparability. However, if scientists were far advanced in this area just a decade ago, now they seem to have been overtaken by other sectors and by industry in particular.

Scientific international collaboration is yet another instrument for facilitating the mobility and learning processes of young scientists. Such actions may well provide the highest added value as far as scientific progress is concerned. Access to new experiences and ideas is the best way to trigger the intellect of young scientists and build on diversity.

A further and recent reason for international collaboration is now imposed by the ethical issues derived from the use of certain technologies that seem to offend the natural order in ways that are unethical. If we take biotechnology as the flagship of the new technologies, it is easy to understand that a global understanding of issues such as the use of sensitive human material or in matters related to genetically modified organisms will be necessary. Added to this, an international understanding about scientific misconduct seems to be in order.

If we turn now to Europe (at large), international scientific collaboration must be at the base of the construction of Europe. Other geopolitical powers with which Europe likes to compare itself have their system reasonably well lubricated. Europe will not get to a leading global position without the close collaboration of its nations. No single country in Europe can take the lead on its own. This seems obvious but it is still widely disregarded by most European nations in spite of the efforts of some institutions (notably the European

Commission). Europe spends a ridiculous amount of its funds (less than 2% of the available S&T budgets) on cross-border scientific and technological projects.

In summary, I have argued that international scientific collaboration is necessary for survival in a globalizing world, in order to keep pace with the extremely rapid changes and advances in discoveries. It is equally necessary to be competitive on global and regional scales. The latter applies in particular to the successful construction of Europe.

Note

1. See, for example, Burke, P. (1999) *European Review*, 7,1.

International collaboration in the fields of life/brain science

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Mega-science projects such as the International Thermonuclear Experimental Reactor (ITER) or space projects, which require large concentrated facilities and workforce, evidently need multinational collaboration. The situation is similar even in the fields of life/brain science as typically represented by the Human Genome Project. These fields belong to the so-called distributed mega-sciences where basic research is conducted in numerous, relatively small laboratories of diverse disciplines. Yet, they are fields developing to a mega scale in terms of both the funding and workforce required, and our expectations of their great impact on future society justify a focused investment of governmental and intergovernmental resources.

In particular, research in the fields of life/brain science is expected to play an invaluable role in our efforts to cope with the serious problems of our ageing society. Advancement in the field of life science is expected to lead eventually to eradication of still fatal and intractable diseases including Alzheimer's disease. Advancement in the field of brain science is expected to lead to the development of complex computers and robots which are expected to compensate for the shortage of workforce arising from the ageing of society.

Because of their distributed nature, a unique form of international collaboration is required in the fields of life/brain science, in which individual basic research projects conducted by researchers across borders must be promoted. Support for such collaboration is presently scarce, apart from the Human Frontier Science Program (HFSP), which specifically aims at the promotion of transcontinental cooperation in the fields of life/brain science, based on its multigovernmental resources and management. Its achievements were reviewed very positively by an external panel a few years ago. I propose that such multinational programmes as this be further launched and expanded by the addition of programmes for constructing databases in a number of world centres and also for training young scientists in these fields, in particular those from developing countries.

Thematic meeting report

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International cooperation is a proven mechanism for promoting excellence in scientific research. Scientists collaborate across borders for a variety of reasons: to bring together the most talented and qualified individuals, to pool intellectual, technological and financial resources, and to effectively address scientific questions that transcend geographical and political boundaries. Cooperation is most straightforward when it is based on agreements between individual researchers although, as always, lack of funding can be a major obstacle, while other difficulties may arise in connection with visas, family relocations, cultural adaptation, etc.

This session of the World Conference on Science focused on an increasingly important set of challenges: those related to the institutional and organizational dimensions of international cooperation. In the past, these challenges were most often encountered in connection with very large projects and programmes that were facility based (telescopes and accelerators, for example). Increasingly, however, they affect small- or medium-scale activities that have to be coordinated internationally. In these areas, there is a crucial role for multilateral organizations: scientific ones (such as those that make up the ICSU family), intergovernmental bodies (such as

UNESCO) and ad hoc, special-purpose structures that are set up on a bilateral, multilateral, regional or global basis.

The presentations and subsequent discussions focused on deriving best practices and recommendations for strengthening international cooperation as a way to advance science and to serve the needs of mankind. A wide variety of cooperative mechanisms was described and reviewed. The main substantive points that can be extracted from the discussion are as follows:

- Regional and global cooperative projects and programmes are of proven value and should be promoted and expanded through allocation of new resources and by strengthening the appropriate institutions. In many cases, important research topics are interdisciplinary and need the involvement of social scientists. New initiatives should be devoted to scientific topics that are of particular benefit to the participating countries, institutions and researchers. The needs of developing countries as regards the challenges of development and scientific capacity-building are of particular importance, especially since an increasing number of important issues must be addressed on a global basis. Despite the difficulties imposed by financial constraints, scientists and authorities in the developing world should strive to play a greater role in the selection and definition of multinational research projects. An equal responsibility rests on those who provide funds for such projects. In any case, the research topics should be defined and selected with the participation of all potential partners. When a significant fraction of the research is carried out in a given country, consideration should be given to providing that country's scientists with a proportionate say in the definition and conduct of the research.
- The unrestricted mobility of scientists should be respected, but the design of cooperative programmes should not create imbalances in the flow of researchers from developing to developed countries (the 'brain drain'). For many countries, the departure of talented individuals is a severe impediment to increasing scientific capacity and creates disincentives to providing training and educational opportunities. A variety of useful practices can be identified to counter this trend: establishing electronic research networks that allow researchers to participate in cutting-edge research while remaining in their home country; establishing national and regional centres of excellence; creating entrepreneurial opportunities in the home country; involving expatriate scientists in cooperative programmes. Policy-makers should concentrate now on programmes that will address the needs of the next generation of scientists who must tackle the difficult challenges confronting the nations of the world.
- In certain regions, and in certain scientific fields, networks of research centres can create a valuable critical mass of expertise on a regional level. Virtual networks are also of proven value, underscoring the importance of improving worldwide Internet connectivity which complements, rather than replaces, direct interpersonal contact. In all cases, local needs and capabilities must be taken into account in programme design. Large regional centres of excellence can be very valuable, but they should not be promoted at the expense of smaller local centres, which may not be able to withstand competition from a bigger facility. Regional scientific associations can provide a critical mass of expertise and advice in such areas as fundraising, information on best practices, hosting large databases and raising the visibility and prestige of science. The support of large, well-known international organizations can be critical to obtaining funding commitments from national governments. International networks of universities that recognize one another's credits and promote student mobility could also be encouraged.
- Enhanced support for cooperative projects should not preclude promoting constructive competition among the world's scientists. Duplication and independent verification have always been hallmarks of the scientific method. International consultation and coordination, however, are always valuable to ensure maximum scientific return.
- The role and significance of very large projects and programmes ('mega-science') continue to evolve, based on the changing needs of scientists and of policy-makers. Many researchers in fields that were traditionally considered to be 'small science' (for example, condensed matter research) are now the primary users of very large facilities (such as neutron sources and synchrotron radiation sources). In public policy, in areas such as health, food production or environmental protection, there is a growing need for the results of large-scale research (for example, genome-mapping projects and Earth-observing systems). For facility-based mega-projects (such as particle accelerators and telescopes), numerous valuable lessons on their optimal design and operation can be learned from past and ongoing collaborations. It has been found that these collaborations often work best when they are strongly supported by the scientific community, when the international arrangements are made during the earliest

stages of development, when the benefits are evenly distributed among participating countries and when adequate provisions are made for access by scientists from countries that are not formal participants. Large distributed programmes (genome, Earth observation, etc.) are especially useful for involving researchers from developing countries while limiting costs of participation in world-class research.

- Large databases are increasingly useful tools in fields such as biodiversity and the social sciences, and in many interdisciplinary areas. Scientists from around the world can participate in developing databases by contributing data, developing analysis tools, providing sites for data storage and helping to certify and maintain the data. Special foresight by funding agencies is needed to foster the development and maintenance of databases and other elements of the global scientific infrastructure.
- International collaboration should be carried out with full recognition of local priorities, constraints and traditions, while giving full credit for local contributions and observing universal standards of equity, transparency and honesty. Examples of positive initiatives were provided during the discussion.
- In many cases, the benefits of cooperation extend well beyond purely scientific ones, with a positive impact on international solidarity, understanding and peace.

Normative issues for electronic publishing in science

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If publication is the chief currency of science, then the scientific journal is where scientists do their banking! By connecting authors and readers, the journal plays a central role in the advancement of science through its certification and communication of knowledge. The journal also helps to establish a priority of ideas, to shape the development of disciplines, to protect the intellectual property of researchers, to maintain the record of scientific progress over time and to promote recognition and stature in one's professional field.

In the modern era, the scientific journal plays an essential role in ensuring the free flow of ideas and information across national boundaries and it is a mechanism by which scientists can fulfil their social responsibilities, including, as noted in the draft *Declaration on Science and the Use of Scientific Knowledge*, to 'communicate with the public'. The latter assumes heightened importance in the Internet environment, where the expanded accessibility of information produces a pressing need for efficient and reliable means to distinguish between information that is useful and that which is not. All of us, as scientists or as citizens, have faced the need to choose among streams of information. We tend to use personal experience and our training to make such choices. But when the latter are not sufficient, we typically rely on a source that we trust to help us evaluate the value of competing bits of information.

Thus, in asking whether data quality is still possible on the Internet, the answer, at least in part, must include the scientific journal. Science is a source of information for both social policy and personal decision-making. As the producer and custodian of scientific knowledge, providing citizens and policy-makers with the knowledge required to make informed decisions rises to the level of a social responsibility that can be discharged, in part, through the scientific journal. Indeed, this responsibility may be especially critical with respect to clinical research, where the findings can have immediate social, economic and health impacts. One example of a way that journals could discharge this responsibility is to include in their electronic versions abstracts for key articles written in lay terms with references to other vetted lay sources of information.

Thus, the authoritative role of the journal can be enhanced in the electronic era if it assumes greater responsibility for bringing order to the vast and largely undifferentiated pool of information on the Internet. Indeed, in the electronic era, this function may well be increasingly viewed as an essential normative role for scientific journals.

There is no doubt that electronic journals create added value in publication through the speed with which they can disseminate information, the size of the audience they can reach efficiently, their improved indexing and search capabilities, their hypertext linkages to other material, their ability to be updated and corrected as needed, their interactivity, which enables real-time exchanges between authors and readers, and their multimedia format, which can incorporate video and sound into text. These features are very attractive to scientists and the number of refereed electronic journals in science, engineering and medicine has increased dramatically since 1991.

To assess whether norms and practices that have developed over time in connection with traditional print publication remain appropriate and functional in the electronic era, the American Association for the Advancement of Science (AAAS), the International Council for Science (through ICSU Press) and UNESCO convened a workshop in Paris, France, in October 1998 to identify the challenges and opportunities for science posed by electronic publishing as part of an effort to develop internationally recognized standards and practices. The workshop participants included broad international and scientific representation. They identified seven distinct issues that merit further dialogue and analysis by the scientific community, policy-makers and the general public.[1] This paper focuses on four of those issues.

Defining a 'publication' in science in an electronic environment

In the print medium, scientific publication is determined and judged to be of value by the appearance of a work in a refereed journal. But what constitutes a 'publication' in an electronic environment, where various modes of communication (e.g. listservs, usenet groups, bulletin boards) exist? The technology of the Internet encourages self-publication and a virtually unlimited period of interaction between author and readers. At what point is there a 'completed publication' subject to formal review? How will priority of discovery be determined in a mixed print and electronic publishing environment? And if posted on the Web in any form, should a writing be considered as 'prior publication' when submitting it to a refereed print or electronic journal?

These and related questions were discussed at the workshop, where participants identified three public versions of a scientific paper. There is the initial posting, perhaps to an e-print server or a personal website. This might be the basis for determining priority. The second is a refereed version with the imprimatur of a journal. The third is a version that incorporates corrections and/or modifications of the second one with extensive links to related materials. One or more of these versions is more or less likely to occur in some disciplines than others. Whatever the practice is, however, the existence of multiple versions creates the possibility of confusion in citation and referencing. Consequently, workshop participants recommended that each publicly available version of a document include a full and clear statement of its status.

The role and form of peer review in electronic journals

Traditionally, peer review has performed two critical functions in science. It serves as a filter to help scientists navigate through the literature, giving them some assurance that the articles appearing in refereed journals meet appropriate standards for accuracy and quality. The system is not foolproof, but it is generally acknowledged as having served science well. A second function of peer review has been to provide authors with feedback so that they may improve the quality of their work. While these functions can be implemented in the electronic medium as well, it is not inevitable. There are concerns that the kind of direct publishing facilitated by the Internet threatens to undermine the role that peer review has played in ensuring the quality and integrity of the print literature; that it will lead to more frivolous and error-ridden data and, in fields related to public health, that it may endanger public safety or patient well-being. The consequences are not trivial and, to re-emphasize a point made earlier, may require a higher level of social responsibility on the part of scientists and of the journals in which they publish. Nevertheless, the interactivity featured in the electronic medium offers the possibility of expanding the peer review process to include a much larger and more open community of peers. This increased scrutiny, with greater feedback to authors, could in principle lead to a much-improved final product.

Participants in the workshop reaffirmed their support for rigorous peer review in digital publishing, while acknowledging that greater openness in the process was desirable. They recognized the value of exploring alternative systems of peer review, but stressed the importance of evaluating the various approaches and emphasized that readers should be made aware of a journal's refereeing policy. Participants also recommended that journals and/or their publishers establish and distribute guidelines for reviewers as a means of maintaining the quality and integrity of the review process, and that more research be done on the potential application of electronic methods for detecting scientific misconduct by authors.

Developing proper linking practices to citations in electronic publications

One of the powerful advantages of electronic publication is the ability to link to other electronic documents, including databases and media other than text. This will require uniform standards for referencing such materials and acknowledging those who produced them. Standards will also need to be developed for 'forward referencing,' whereby links are made to materials that become available after the original paper is published, a unique feature of electronic media. The use of a citation implies that the documents cited are available in the form in which they appeared when cited. With the passage of time, however, digital items may be withdrawn, updated or otherwise altered.

Workshop participants clearly realized the need for a convention on the citation of electronic material. At a minimum, the citation should identify the version being referred to or read, along with appropriate metadata. Participants believed that more precise standards for identifying digital objects, including all referenced work, must be developed.

Privacy and security issues in electronic publications

The Internet can provide publishers of electronic publications with more information about their users than ever before. Not only can publishers and editors track the precise reading habits of their users/subscribers, they can also aggregate this information and use it for various other purposes – marketing, repositioning content to make it more visible and matching content with user interests. While such practices can help make publications more responsive to the interests of users/subscribers, they do pose potential intrusions of privacy.

Participants in the workshop recommended that journals adopt guidelines that include policies that disclose to users the nature and possible uses of the information collected, and that these policies be visibly posted on a journal's Internet site. Individually identifiable information should not be divulged without the permission of the person it identifies and users should have the opportunity to opt out of the collection of their personal data. Ways will also need to be found to implement security provisions so that they do not create new barriers to access to scientific articles and data by legitimate users/subscribers.

The issues associated with electronic publishing in science are complex. How the scientific community and related institutions respond to these issues will have much to do with how well science exploits the full potential of electronic publishing while sustaining the quality and integrity of the published record of science.

Note

1. The full report of the workshop on Developing Practices and Standards for Electronic Publishing in Science held in UNESCO (12-14 October 1998) and the individual papers prepared by participants are posted on the web at http://www.aaas.org/spp/dspp/sfrl/projects/epub/standard.htm

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Scientific data in the Internet era

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This meeting has addressed many issues related to all types of scientific information, from its initial publication through to its impact on society. In this paper, I will address specific issues related to scientific data, especially those of concern in the Internet era. By scientific data, I mean the quantitative information used to express our understanding of nature. Some types of scientific data are listed hereafter:

- observations;
- experimental measurements;
- calculational results;
- structure and composition of substances, species and systems;
- properties and the conditions under which they are valid;
- process diagrams;
- reaction pathways;
- other quantitative information.

Though often expressed numerically, scientific data can also be communicated as text, pictures, diagrams and symbols. Two of the most complete descriptions of scientific data are given in Rossmassler and Watson (1980) and Rumble and Smith (1989).

The following discussion reflects the tremendous advances of the last few decades. Today, we have the unprecedented ability to observe, manipulate and control nature on every scale, from its most fundamental level, on an atom-by-atom basis, or in viewing the entire universe. Accompanying this new experimental capability is the explosion of computer power, which gives us more computational ability than was ever imagined 50 years ago. At the same time, robust and accurate modelling and simulation methods allow us to exploit this computer power. And telecommunications and network growth provide instant connectivity at any time and to any place. With the invention of the World Wide Web, this connectivity is easy to use and exploit. One result of these four advances is what has been termed the ‘scientific information revolution’.

The scientific information revolution presents important challenges. The enormous volume of observations makes it impossible to examine and understand all available data. The following prediction by Leonard Kleinrock is becoming uncomfortably true: ‘We possess today the power to create computerized chaos on a scale far surpassing anything seen before.’

In the rest of this paper, I will discuss three aspects of the scientific information revolution: data usability, data quality and data exploitation. Other papers coming from this session discuss additional issues equally as important to scientific data specifically as they relate to more general scientific information. These issues include intellectual property, archiving, dissemination, economics and accessibility by scientists in developing countries. Similarly, the discussion on usability, quality and exploitation applies in many ways to all of scientific information.

Data usability

It is a fact that scientific data resources are primarily built from the data generation viewpoint; that is, the collected data are not organized by or for their potential use, but rather by the scientific discipline that generated them. By contrast, users of scientific data, such as scientists developing new experiments and engineers designing new products and processes, are generally indifferent to how data have been generated. Their concern is finding the needed data. In point of fact, users generally need data from a variety of sources, most of which have different authors, different formats and different representations (units, etc.). Further, in most cases, only a small amount of data is extracted from any one data source. Consequently, even in an environment in which data access is computerized, the burden is on the user to transform the data into common formats and representations to ensure data uniformity.

In most situations today, individual users must confront data incompatibility problems. Standards are needed for data formats, nomenclature systems and definitions. Obviously, standards provide an efficient and cost-effective way to take advantage of the multitude of available data resources. For standards to be accepted, however, scientists must develop the criteria so the resulting nomenclature and definitions reflect a scientific consensus. International bodies such as the ICSU Committee on Data for Science and Technology (CODATA), the International Union of Biological Sciences (IUBS) and the International Union of Microbiological Sciences (IUMS) have already begun working on scientific data standards so that new data collections can be easily used and will be of maximum value for 21st century science and engineering.

Data quality

Over the four centuries of modern scientific research, science has developed many conventions to improve the quality of scientific information. Peer-reviewed journals, open scientific discussions, literature reviews and handbooks of evaluated data are but a few examples. In the last decade the Internet explosion has seemingly overturned many of these conventions. As a result, anyone can write a paper or establish a data collection that is quite professional in appearance and distribute it on the Web to compete with other information resources, even though the Web product has not gone through the peer review system or any other quality control process. Quality control in scientific communication is critical to the success of the modern research enterprise.

In fact, given the amount of information now being made available, quality assessment is more important than ever in science, and the scientific community must undergo complete re-examination of the procedures by which it has traditionally assessed data quality. Others have discussed the changes in scientific publishing, so I will concentrate here on the quality of scientific data collections.

As mentioned earlier, most data users are not experts on how data were generated. Even if they could find the needed data among hundreds of thousands of papers, they would not know whether or not the data were reliable. To this end, formal data evaluation programmes are receiving renewed attention. Several examples are evident. Large-scale modelling of global climate change is being done using computer models of a complexity almost unimaginable. Not only are the fundamental chemical reactions occurring at various levels of the atmosphere included in detail, but also included is coupling between the atmosphere and the oceans. Hundreds of different types of measurements – chemical reaction rates, temperature and wind observations, ocean salinity distributions, ocean and atmospheric currents – are used as input. The potential for human-assisted climate changes, such as ozone depletion or carbon dioxide warming, and the economic consequences of remedial actions, makes it imperative that the quality of the data used in these models be as high as possible. Groups such as CODATA, the International Union of Pure and Applied Chemistry (IUPAC) and the World Data Centers make concerted efforts to bring together international teams of experts to assess data quality.

In addition national programmes, such as those supported by the National Institute of Standards and Technology (NIST) in the USA and Gosstandardt (Russia), and discipline-oriented programmes, such as the Cambridge Crystallographic Data Centre and the Protein Data Bank, all provide expertise in reviewing data quality and providing feedback to the measurement community on possible improvements. The greatly increased accessibility of data brought about by the Web makes such quality control efforts even more valuable.

Data exploitation

Large-scale data collections, of known and high quality, open amazing opportunities for 21st century science. We can now create comprehensive data collections that can become a source of new scientific discovery. Some of this can be achieved through the development of new approaches in knowledge discovery software, such as data mining and genetic algorithms. Other forms of discovery will be aided by new scientific insights. What is clear is that our ability to do this kind of research is still in its infancy. New software, algorithms and scientific insights make any projection of possible discoveries tenuous at best. However, consider the data collections soon to become available: a complete catalogue of astronomical objects, the human genome, genome maps for many other species, global biodiversity checklists, decades-long climate details, palaeontology records, structural data of all known crystalline substances, etc. Each represents a resource not available even two decades ago.

Take, for example, the structure space spanned by inorganic compounds, such as that formed by a combination of two or three metallic atoms, one to four oxygen or sulphur atoms and up to four halogen atoms. The number of possible compounds that could be synthesized is enormous, even with combinatorial chemistry techniques. However, with complete databases of the structure of known inorganic and metallic compounds, materials scientists can systematically explore the known composition and structure space to predict new combinations with potentially interesting properties. This is already a cornerstone of modern drug development.

The richness of these data collections also relates to one major scientific challenge of the next century, complexity. Real systems of atoms, substances, cells and species include 10^6 to 10^{23} members. Science has already shown that the behaviour of real systems is more than the sum of the behaviour of the individual components. For example, if we consider that the human body has about 10^{13} cells, can we say that, because we know the structure of several thousand biomacromolecules, the behaviour of cells, tissues, organs and even species is immediately calculable? Comprehensive data collections that capture behaviour and properties on one scale can be exploited for insights into how nature works on a larger scale. The models that will be used to describe complex behaviour will be based on high-quality data collections.

Summary

The turbulence of the scientific publishing enterprise often seems a distraction to scientific progress. However, with regard to scientific data, the primary factor should be the excitement that is generated by the scientific information revolution. Comprehensive data collections pave the way to new and better science. To capture the possible gains, the scientific data community must work vigorously to improve data usability, ensure the highest possible data quality and develop new methods to use data collections for knowledge discovery. The return on this investment will be a richer and better science.

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The development of the Internet in China and its influence on sharing of scientific information

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Human society has come from the Industrial Age to the Information Age and information has become a very important resource for the development of human society. At present, the developed nations, which account for 20% of the world population, own 80% of the world's information, whereas the developing nations, which make up 80% of the world population, own only 20%. The Information Highway and the Internet have realized the convenient sharing of information in a worldwide sphere. The Asian nations should make full use of this opportunity and speed up the basic construction of the information industry, so as to avoid a vicious circle of lack of information and a lagging economy.

The Internet will bring great changes to education, science, technology, commerce and people's lives; the financial crisis in Asia has not stopped the development of the Internet. It is estimated that, in the year 2000, there will be 28.5 million Asian families linked up to the Internet. And by the year 2001, the income from electronic commerce based on the Internet will have increased rapidly from US$ 600 million at present to US$ 30 000 million. Among all the Asian nations, Japan owns the largest number of computers on-line, followed by China, Hong Kong and Singapore. The Singapore Government has been making unremitting efforts to expand the bandwidth and the No. 1 Project of Singapore placed emphasis on connecting the telephone lines with the cable television network using a high-frequency optical cable line. Singaporean families will be able to use the high-speed line based on the Internet to realize functions such as video services, cable news, tele-education and shopping on line by paying only US$ 21 every month.

The basis for sharing scientific knowledge is the development of computers, networks and communications. In recent years, sales of computers in China have increased rapidly. In 1997, personal computer (PC) sales amounted to 3.4 million; in 1998, the figure was 4.7 million, with the PC made in China taking up most of the market share. It is estimated that, in 1999, sales will reach 6 million and, by 2000, 10 million. Chinese computer market sales will be expected to exceed sales in Japan at the beginning of the 21st century. China has built up a telecommunications network centred around optical cable lines and accompanied by multiple means of the communications network such as microwave, satellite, telephone, mobile phone, digital communications, multimedia communications, etc. The networks cover cities and towns all over the nation and reach telecommunications networks all over the world. The optical cable trunk line reaches all capital cities and 70% of big cities. The capacity of the switchboards of telephone bureaux all over the nation reaches over 200 million. And the capacity of the switchboard for mobile phones reaches 60 million users. The digital data communications network reaches 90% of the cities and counties of the nation, and the public computer network covers all cities and districts and most of the economically developed counties. Households with telephones make up 13% of total households and over 40% of city households.

Development of networks in China

Since China first linked up to the Internet in 1994, the network has developed rapidly. At present, there are four large networks in China: the Chinese Science and Technology Net (CSTNET), the Public Computer Net (CHINANET), the Chinese Education and Research Net (CERNET) and the China Gold Bridge Net (CHINAGBN). The number of network users is also increasing rapidly; they now amount to 3 million people. It is estimated that, by the end of the year 2000, the number of network users will be 10 million. Among the users, 79.2% are young people aged from 21 to 35.

As far as the kind of information the users wish to get from the Internet is concerned, 67.2% of users wish to get scientific information; 63.3% wish to get information on entertainment and sports; 45.1% economic and political news; 43.7% commercial information and consultation; and 26.1% financial and stock information. It can be inferred that the information most wanted on-line for Chinese users of the Internet is technological information. At present, over 90% of the scientific information on-line is in a language other than Chinese. China is trying to build up information resources in Chinese on the Internet. The development and construction of scientific information and databases, together with the on-line service of scientific information as a basic work, contributes to the promotion of the information industry in the area of scientific information. The development and construction of scientific information and databases concentrate on the following fields.

Natural resources and sustainable development

Based on long-term investigation, statistical evaluation and on-the-spot verification, the Natural Resource Comprehensive Investigation Committee of the Chinese Academy of Sciences has been constructing a comprehensive database of Chinese natural resources since the end of the 1980s. The database includes several aspects such as resource, environment and economic statistics. The categories are divided into water, land, climate, mineral resources, energy, tourism, sea resources, as well as population and labour force, macroscopic environment, agricultural economy, industrial economy, etc. The database is now available on the Internet (http://www.cern.ac.cn/njh).

In 1994, the Chinese Government produced a 21st Century Agenda setting up the strategic direction of sustainable development of the national economy. In 1997, the administrative centre of the 21st Century Agenda organized a demonstration project on the sharing of information on sustainable development. The main content included natural resources, natural disasters and environmental preservation. As many as eight ministries are involved in the cooperation project. Once the system has been constructed, the sharing of information will be realized in the areas of land use, vegetation and the ecological environment, species, forest, climate and meteorology, water resources, quality of crop seed, mineral resources, etc. Within three years, an information sharing system under the network environment will be constructed with the functions of information consultation, search, integration, analysis and synthesis (http://www.acca21.edu.cn).

Environment and ecology research

Serious environmental problems and the increasing pressure of population made China attach much importance to the environment on which human beings rely for survival.

- The valuable statistics on Qingzang Highland and the South and North Tianshan Mountain, which have accumulated throughout the years, were organized and standardized to form the database on the Chinese Frozen Circle. The information will be published by means of a Web database.
- A database has also been constructed based on the collection and organization of the statistics on Chinese environmental, social and economic data in different historical periods. China has kept a constant record throughout history; thus, it

has the advantage of having research on the change in climate and environment over a period of around 2 000 years. Based on historical materials such as history books, annual records and regional histories, the Chinese Academy of Sciences has constructed a database on The Environmental Change and Social, Economic Development of China During Different Historical Periods. The time-span of the database runs from 137 BC to the year 1949 (http://159.226.115.77/climate/paleo).

- The construction of the Chinese Environmental Research Net (CERN) began in 1988. After 10 years of hard work, based on the original 100 field observation stations and experimental stations, it was constructed as a network capable of carrying out long-term observation and research on the environment and ecology across the nation. Thousands of researchers in the 21 ecological and geological research institutions of the Chinese Academy of Science took part in the project and a series of important successes were achieved (http://www.cern.ac.cn).

Biodiversity

Since the United Nations Conference on Environment and Development (UNCED) held in Rio in 1992, China has made distinct efforts to develop its information system on biodiversity:

- The Information Center for Biodiversity has constructed a Chinese Bio-diversity Information System (CBIS), which includes major statistical resources from five subdivisions (http://cbis.brim.ac.cn):
  - the subdivision on plants in the Plant Research Institute of the Chinese Academy of Sciences;
  - the subdivision on animals in the Animal Research Institute of the Chinese Academy of Sciences with a database of more than 13 000 categories of animal species;
  - the subdivision on micro-organisms in the Micro-organism Research Institute of the Chinese Academy of Sciences with a database on species of Chinese mushrooms;
  - the subdivision on freshwater organisms in the Wu Han Hydrobiology Research Institute, with species categories, endangered and protected species database;
  - the subdivision on halo-bios in the South Sea Oceanography Institute of the Chinese Academy of Sciences.
- The Animal Research Institute of the Chinese Academy of Sciences in Kun Ming has constructed a Database on Chinese Environmental Preservation Areas. The database adopted the software package recommended by the International Wild Life Preservation Association. The software has been translated into Chinese, adapted and expanded to carry out the management of the database.
- The Crop Species Resource Institute of the Academy of Agriculture has constructed a Database on National Crop Seed Quality Resources (http://icgr.caas.net.cn).

Chemistry and materials

In 1993, China implemented patent protection for medicine. China also adopted the international standard on intellectual property. The research and development of creative, originative and competitive medicine has become a must. It is for this purpose that the old chemistry database has been adapted to a new medicine database to research and design new medicine with computer assistance.

Statistics on the erosion of materials in the natural environment and the database on this has been a long-term project supported by the National Natural Science Foundation of China. The database has accumulated millions of data entries since it was begun in the 1950s.

Besides the above-mentioned fields, in the past two years many websites dedicated to providing a scientific information service have appeared. Among them are the Chinese Science and Technology Information Net, Chinese Engineering Technology Net, Chinese Engineering and Aviation Technology Information Net, Chinese Ocean Information Net, Chinese Earthquake Information Net, Chinese Agricultural Technology Net, Chinese Forestry Technology Net, Chinese Materials Technology Information Net and Patent Search Net.

The information highway shortens the process to modernization; the developing countries in Asia have a long way to go. In the 1970s, China had not opened up. Chinese researchers could not get timely knowledge of development abroad. Thus, many of their hard-earned research efforts were either a lot of unnecessary trouble or conflicted with patents abroad. Today, using electronic information, which is highly effective, researchers can know about the latest developments of research work in a particular field. This will help them to choose the right project and benefit from fellow researchers' experience and thus avoid repetition while saving time and energy. The information highway also shortens the process of publication and communication, trade and transformation of the fruits of research into productive forces. In this way, the fruits of research of one nation become the fruits of the whole world. Scientists publish their academic thesis on line and hold long-distance academic conferences on line to discuss academic problems. Scientists from different nations can cooperate on carrying out research on one topic through on-line discussion.

The information resources in the developing nations of Asia are a great distance from those in the developed nations of Europe and North America. In the international database market, the distribution of database products is as follows: North America accounts for 64%, Western Europe 28%, Asia 4%, Australia 20%, Eastern Europe 1%, Africa and South America 1%. The sum total percentage of developing nations is less than 5%.

China has a large population and a vast territory. Therefore, it is uniquely symbolized by its geographical surroundings, geological structure, climate distribution, human genetics and species, etc. Meanwhile, it boasts its own scientific information resources and constitutes an important part of global information resources. However, due to the shortage of funding and serious ‘brain drain’ of technical personnel, work on improving the China Information Resources Database has been left as the proposal of leading experts, a large amount of information has not been processed and much of the valuable historical material remains untouched. For example, it is reported that climate research done in China took form before Christ. Such factors as climate change and the consequential shift in human activity have been recorded in the Chinese civilization for over 2 000 years; it has become a precious heritage for research on the human being and his environment. It is highly recommended that international organizations, developed countries, developing countries and concerned Chinese institutions cooperate to tap the information resources and contribute to the cause of full access to global scientific and technological resources.

Recently, four Chinese universities and colleges launched a programme to recruit students through the Internet to realize the goal of implementing tele-education by means of the Internet and modern science and technology. This will have a profound impact on the economic and social development of remote and poverty-stricken areas in China. In consideration of the social need for education in China and the lower ratio of people who have received higher education, it has just begun the first stage of an on-line university and thus promises great potential for fast development. The developed countries have long enjoyed a remarkable advantage in tele-education equipment and teaching resources; it is our sincere hope to carry out extensive cooperation in this regard.

Seen from the experience of developed nations, the development of scientific information resources has direct and indirect social and economic returns. It has a long-term strategic benefit. Governments can have a direct influence on the level and results of the development and use of information resources by making policy on capital investment, tax, information legislation and human resource education, etc.

From the perspective of human resources, a lot of excellent young people from China and other Asian countries have gone to the developed countries. They have devoted the most valuable time of their lives, from the ages of 20 to 40, to the enterprises of the developed countries and have contributed to the high-tech industry and economic development there, whereas the developing countries in Asia, including China, have invested in vain in the education of those excellent young people from primary school to college and graduate school. Some university professors in China have said that the developed nations should make some compensation for the Chinese people’s investment in education, and that those nations have an obligation to help developing nations in the sharing of scientific information resources and to impose less strict limitations on the transfer and export of high-tech products. The developing nations in Asia should take advantage of the Internet Age and make full use of international scientific information, so as to bridge the gap between developing nations and developed nations.

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This paper is based on the article *A Brief Analysis of the Development of Chinese Scientific Information Resources and the Present Situation of the Internet* by Hu Yaruo, Zhang Hui and Xiao Yun from the Chinese Committee of the ICSU Committee on Data for Science and Technology (CODATA), and the report *Research on the Development and Use of the Chinese Scientific Electronic Information Resources*.

Sharing scientific knowledge through publications: what do developing countries have to offer?

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> *'El pasado ha sido escrito; debemos escribir ahora, todos juntos, el futuro'*
>
> FEDERICO MAYOR, OPENING SESSION OF THE WORLD CONFERENCE ON SCIENCE, BUDAPEST, JUNE 1999

Scientific activity, on the one hand, and the publishing industry, on the other, have never been equally well distributed around the globe and the current situation is no better. A small number of countries dominate world publishing today and a few commercial publishers of scientific journals control a market of tens of millions of dollars, with benefits of up to 40% (see for example *El País*, 1999). All the developing countries taken together, with 80% of the world's population, produce only 10% of the more than half a million registered ISSN titles (see Table 1) and when it comes to titles in science the percentage is estimated to be considerably lower, of the order of 3-4%. Yet for the developing countries themselves, the sustained production of a few thousand journal titles already represents a considerable effort.

Table 1. **World distribution of active serial titles**[1]

REGION OR COUNTRY	NO. ISSN TITLES	% ISSN TITLES	NO. ULRICH'S TITLES	% ULRICH'S TITLES	NO. ISI TITLES	% (ISI/ISSN)
Africa	9 574	1.8	4 249	3.0	15	0.157
Latin America & Caribbean	15 418	2.8	5 166	3.6	25	0.162
Developing countries in Asia	29 503	5.4	10 148	7.1	58	0.197
Japan	19 740	3.6	5 419	3.8	97	0.491
USA	96 763	17.8	50 136	34.9	2 844	2.939
Canada	41 924	7.7	5 508	3.8	123	0.293
Oceania	29 451	5.4	4 226	2.9	91	0.309
European Union	240 622	44.3	49 131	34.2	2 506	1.041
Rest of the world[2]	60 566	11.1	9 740	6.8	362	0.598
Total	**543 561**	**100**	**143 723**	**100**	**6 121**	**1.126**

1. Sources: ISSN CD–ROM 1997; Ulrich's Plus on CD–ROM 1997; ISI Source Publications 1997. Data taken from Cetto (1998).
2. 'Rest of the world' comprises basically Eastern European countries and others that do not form part of the European Union.

These journals have in general poor distribution and visibility, and are normally under-represented in the international databases and indexing services (see Table 1). What has been traditionally true for print-on-paper journals applies now as well to their electronic counterparts. The reasons for this poor presence are various, relating to important aspects such as the limited local scientific capacity, the weakness of the publishing sector and, more recently, a poor telecommunications infrastructure and the dominance of foreign and transnational market forces. Against all these drawbacks, developing countries must make special efforts to increase their capacity to produce, publish and distribute scientific information, as a contribution to their own scientific development and to international science.

It is important that the different countries have their own motivation for supporting and carrying out scientific research and that they do it according to their needs and interests. This does not conflict with the idea that science is international; on the contrary, precisely what gives an international character to science is the fact that scientists from all over the world contribute to it. They do this by publishing in journals of their own country as well as in others that are produced abroad and serve to validate and distribute their work more widely on an international scale. Which does not mean that all scientific production has to end up being part of 'international science'; much of it is only of local or regional relevance and is not necessarily made with the purpose of sharing it with colleagues all over the world. In fact, as has been recently pointed out, 'many English papers, for instance, are as domestic as the Spanish ones... yet English-language journals that publish domestic science get into the SCI, whereas the equivalent Spanish-language journals do not' (Rey-Rocha *et al.*, 1999).

These and related issues have been the subject of regional and international meetings devoted to discussing current problems faced by scientific publishing in both North and South, and to analysing more specifically the potentialities of electronic communication and information technologies and the impact of these on scientific publishing (see for example Shaw and Moore, 1996; AAAS/UNESCO/ICSU, 1998; INASP/British Council/ICSU Press, 1999; Cetto and Hillerud, 1995; Cetto and Alonso, 1999). It has become evident from these discussions that not only must access by the South to information produced in the North be greatly improved and facilitated by appropriate economic and technical measures, but also that the flow of information within the South and from South to North must increase considerably. This means, in particular, that the local communities of developing countries must participate, along with the rest of the world, in all activities related to scientific publishing – including the development and use of electronic publishing – and that they must establish close working links among themselves in order for them to benefit from common experiences, to become stronger partners at the international level, and to take part also in related business.

A number of initiatives that use the new technologies for the benefit of scientific journals from developing countries are now under way and can serve as models of good practice to be promoted, developed or replicated and supported internationally. It is clear that there is in this field an as-yet barely explored potential for partnerships between publishers and/or activities on a South-South and South-North basis.

There are, on the one hand, a few notable examples of efforts of collaboration involving both developed and developing countries. The results have been more clearly positive when such efforts have been jointly defined and based on genuine cooperation rather than directed at the intended beneficiaries. However, even with the best of intentions, cooperation, especially between uneven partners, has its limitations; it cannot replace, but only complement, the efforts needed from within to strengthen the scientific capacities in developing countries. This applies to scientific publishing as to any other aspect of scientific activity.

A clear instance of application of these principles is given by the projects developed and promoted by the International Network for the Availability of Scientific Publications (INASP), such as its training programmes and workshops for African librarians and editors, the electronic system to promote African-published scholarly journals, called African Journals On Line, and INASP-Health, which is designed for community information provision on health (http://www.oneworld.org/inasp/).

Regional cooperation, on the other hand, can be an especially appropriate tool when the countries involved have similar cultural and historical backgrounds and use common languages. This applies, in particular, to Latin America. It is only natural, therefore, to see regional projects on electronic publishing developing recently in this region; in fact, it is somewhat surprising that there are only a very few such projects. The first important one, quite successful and well established, is BIREME, the electronic bibliographic information system on health and biomedical sciences, sponsored by the Pan-American Health Organization and covering the whole continent. The creators of BIREME are now engaged in the development of SciELO, an electronic on-line system for full-text scientific journals, starting with a selection of Brazilian journals and intending to extend its geographical coverage (http://www.scielo.br/cgi-bin/).

A further project with regional coverage, created in response to a recommendation of an international workshop that took place in Guadalajara, Mexico in 1994 (see Cetto and Hillerud, 1995; Cetto and Alonso, 1999), is LATINDEX, an electronic information system on and for scientific journals (http://biblioweb.dgsca.unam.mx/latindex/). The system was initially intended to cover Latin America and the Caribbean, but Spain and Portugal have joined in. Present regional resource centres associated with LATINDEX are located in Argentina, Brazil, Chile, Cuba, Mexico, Portugal, Spain and Venezuela. The first product, a Directory of active scientific and technical periodicals, contains a basic description of about 7 000 titles, more than was originally expected on the basis of the generally poor knowledge of what is published in the region.

As a result of these initial experiences, important outcomes that can contribute to a better sharing of scientific knowledge both within the South and with the North have been identified, such as: improvement in the quality, circulation and visibility of the scientific literature published in developing countries; linking up of the scientific community in its own languages and promotion of the flow of information within the South; identification and strengthening of areas of scientific research of particular relevance to developing countries; better use and management of the bibliographic information produced in these countries; and provision of bibliographic by-products to support studies on science and science-policy planning and to obtain bibliometric indicators on scientific activity.

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Copyright versus freedom of scientific communication

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Recent developments in copyright law and practice, many inspired or triggered by the new digital networked environment, have the potential to negatively affect the freedom of scientific communication. In this paper a number of these developments will be briefly examined. The paper demonstrates that it is critically important for the global scientific community to become actively involved in the international, European and national legislative process to protect scientific freedoms against further erosion.

Database protection

It is a maxim of copyright law that copyright protects only the form (expression) of a work, not its contents (ideas). Thus, the fruits of an author's labour are secured against unauthorized reproduction, whereas the freedom of expression and information, so vital to the world of science and other segments of society, remains intact. The advent of the European Database Directive, adopted by the Council of the European Communities and the European Parliament in 1996[1], has undermined the traditional idea/expression dichotomy. A novel 'database right' has been created which protects the 'contents' (e.g. facts or other items of information) of a 'database' (i.e. any compilation or collection of information in electronic form or other media), on condition that the database producer has substantially invested in the database.

This new right, which exists independently from copyright, prohibits the unauthorized extraction or reutilization of a substantial part of the protected database. The right expires after 15 years upon completion or first publication of the database, but is revived by any subsequent 'substantial' investment, e.g. by being regularly updated. Legislation similar to the Database Directive is currently under way in the USA and elsewhere.

In protecting collections of data previously in the public domain, the database right affects the freedom of scientists to download or reutilize data sets, e.g. from government-produced databases. Even if the Directive does allow national legislatures to create (limited) exceptions to the database right 'for the purposes of illustration for teaching or scientific research', in implementing the Directive a number of Member States of the European Union have failed to do so.

The proliferation of copyright in the digital environment

In recent years the expansion of the Internet into a global mass medium has had a profound impact on the law of copyright. On the international level, the intergovernmental discussions within the framework of the World Intellectual Property Organization (WIPO) have led to a pair of treaties (on copyright and neighbouring rights respectively) that were adopted at the WIPO Diplomatic Conference in Geneva in December 1996[2]. Both treaties particularly deal with the use of copyright-protected works, performances and sound recordings in digital networks, such as the Internet. Authors, performers and phonogram (i.e. record) producers are granted a broadly worded exclusive right of communication to the public, covering interactive services and delivery on demand. The Diplomatic Conference could not agree on a proposal to extend the exclusive right of reproduction to include the temporary storage of a work in computer memory; this controversial issue is still undecided on the international level. Ratification of the WIPO Treaties is currently being considered by many signatory states, or even completed as in the USA, where the so-called Digital Millennium Copyright Act was enacted on 9 October 1998.

In the European Union, ratification of the WIPO Treaties is still under way. In December 1997, the European

Commission adopted a proposal for a European Parliament and Council Directive 'on the harmonization of certain aspects of copyright and related rights in the Information Society'. Following discussions in the European Parliament the proposal was substantially amended in May 1999[3]. The aim of the proposed Directive is to implement the provisions of the WIPO Treaties in a uniform and consistent manner for the entire European Union, at a higher level of protection than the WIPO minimum. Final adoption by the European Council and the European Parliament is not expected before the year 2000.

Unlike the WIPO Treaties, the proposed Directive does provide for a definition of the right of reproduction to include all acts of temporary or transient copying that occur during acts of browsing or network transmission (e.g. 'caching'). The expanded reproduction right would imply nothing less than a right to digital usage. Such a use right is, however, antithetical to the traditional principle that copyright and neighbouring rights do not protect against acts of consumption or reception of information. Reading a book, watching television and listening to the radio involve basic rights of privacy and freedom of reception, and have, therefore, never been considered as restricted acts. Arguably, the same must be true for the digital environment.

The proposed Copyright Directive would provide for a limited exception to the reproduction right permitting 'temporary acts of reproduction such as transient and incidental acts of reproduction which are an integral and essential part of a technological process, including those which facilitate effective functioning of transmission systems, whose sole purpose is to enable use to be made of a work or other subject matter and which have no independent economic significance'. As amended the provision (Article 5§1) would apparently allow (economically 'insignificant') forms of caching without the right owners' consent. Earlier versions, notably the provision adopted by the European Parliament in its first reading on 10 February 1999, suggested otherwise, thereby causing grave concern among Internet access providers, universities and other intermediaries.

Somewhat paradoxically, yet another piece of European legislation currently proposed would immunize Internet providers from unwanted copyright liability. In November 1998 the European Commission adopted its proposal for a so-called E-Commerce Directive. Following discussion in Parliament, an amended version was introduced in August 1999[4]. The proposed directive would establish a complete exemption from liability for providers playing a passive role as 'mere conduits' of information provided by third parties and limit liability for other intermediary activities such as hosting or caching.

An especially controversial part of the proposed Copyright Directive is an attempt to harmonize the set of copyright limitations (exceptions) already existing in the Member States. The proposal contains an enumerative list of limitations that national legislatures might maintain in the future; exceptions not listed would no longer be allowed. The amended proposal leaves some room for an exception for scientific purposes, which is rather narrowly defined as follows: 'use for the sole purpose of illustration for teaching or scientific research, as long as the source is indicated and to the extent justified by the non-commercial purpose to be achieved, on condition that the rights holders receive fair compensation'. The proposal compares unfavourably to exceptions currently existing in many Member States in that scientific freedoms are often granted irrespective of 'commercial' purpose. Moreover, in many countries exceptions are drafted as outright limitations, not requiring compensation to rights holders. In sum, adoption of the proposed Directive would impinge on scientific freedoms as they exist today in many Member States.

On a more general level, there is an increasing feeling of uneasiness among consumers, scientists, intermediaries and universities that the 'delicate balance' between intellectual property protection and user freedoms is being disturbed by the high level of protection envisaged by the European legislature. User groups are afraid that the expanded reproduction right will give rights holders complete control over the entire communication chain on the Internet (service providers, access providers and consumers). Thus, the Directive might be instrumental in a movement towards vertical integration and stifle competition and innovation on the Internet.

Contractual and technological protection

Publishing contracts pose an additional threat to scientific freedoms. Publishers of scientific articles routinely insist on contractually acquiring from authors, prior to publication, all copyrights in the article, including the so-called 'electronic rights'. As a consequence, scientists are prevented from disseminating their own, unpublished articles on private or university-owned websites, e-print servers, electronic newsletters or discussion lists. Moreover, scientists and their employers (mostly universities) will be prevented from storing their own articles in scientific databases. Instead, scientific institutions are forced to buy back the rights to re-utilize the works in electronic form, often at premium prices, from scientific publishers. The scientific community would be well-advised to follow the example of other sectors of the information industry (e.g. literary publishing) and develop, preferably in collaboration with scientific publishers, model publishing agreements that reflect a fair balance between the interests of authors, institutions and publishers.

Whereas in their role as authors scientists regularly ‘sign away’ all their rights to scientific publishers, as users of electronic databases they are increasingly confronted with draconian ‘user licences’ imposed by publishers that allow for only marginal user freedoms. These user licences have the potential to even further restrict user freedoms by contractually overriding existing copyright limitations. In order to preserve basic user freedoms it is important that copyright limitations protecting these freedoms be granted imperative status, so they cannot be overruled by contract. Both the European Database and the Software Directive contain a number of such non-overridable exemptions, e.g. to allow users of databases to download and reutilize insubstantial parts of licensed databases. Unfortunately, the proposed Copyright Directive does not contain any similar provisions.

In addition to copyright and contract, publishers are expected to resort to other practical or legal means (encryption, trusted systems, etc.) to create additional layers of protection. Both the WIPO Treaties and the proposed Copyright Directive prescribe an extra level of legal protection against circumventing these so-called technological measures. As a result, scientific freedoms will be further compromised.

Notes

1. Directive 96/9/EC of the European Parliament and of the Council on the legal protection of databases, 11 March 1996, OJ No. L 77/20 of 27 March 1996.
2. WIPO Copyright Treaty, adopted by the Diplomatic Conference on 20 December 1996; WIPO Performances and Phonograms Treaty, adopted by the Diplomatic Conference on 20 December 1996.
3. Amended proposal for a European Parliament and Council Directive on the harmonization of certain aspects of copyright and related rights in the Information Society, Brussels, 21 May 1999, COM (1999) 250 final.
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Access to information now and in the future

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The underlining assumption behind my presentation is that the progress of science depends on access to the record of past scientific endeavour.

The cornerstone of the scientific record for the past 300 years has been the refereed journal article published in a reputable scientific journal. Over this period a sophisticated and complex library and information system has developed to ensure that these articles are properly indexed and accessible from the libraries which hold them. Because print on paper is a relatively stable medium, because journals have been published in significant numbers and because they continue to contain information that is of value, major scientific and national libraries have retained their copies. Thus, to a very great extent, the corpus of science as published in scientific journals, from the first issue of the *Philosophical Translations of the Royal Society* onwards, is still available today to all who need access to it.

The British Library, for example, receives requests for some 15 000 scientific, technical and medical articles every day from all over the world. Hundreds of these will be for articles published over 50 years ago.

As we have already heard at this meeting, we now see a move towards electronic publishing in science driven by the advantages of speed, access and novel ways of combining and communicating data and information.

It is difficult to obtain an accurate assessment of how many peer-reviewed journals and articles are now published only electronically (the vast majority are still electronic versions of printed publications); nevertheless, the trends are clear and the reasons are understandable. Yet, the processes to ensure that these scientific electronic publications will be available in the future are not in place. Digital storage media have much shorter life spans than paper and require access technologies that are changing at an ever-increasing pace. The time-frame between the creation of a current publication and the need for its preservation is becoming shorter. The scientific and technical community therefore risks the loss of valuable information without an adequate infrastructure for digital archiving and preservation.

Such structures are not there and that is why some commentators are saying that we are entering a Digital Dark Age.

The International Council for Scientific and Technical Information (ICSTI) recently undertook an international survey[1] to get some understanding of the current state of the art and state of practice of digital archiving. It is clear that there are many different stakeholders who can and must contribute to a satisfactory solution. Authors, primary publishers, secondary services, librarians, national libraries: all have a role to play. Many have already declared an intent to preserve certain items, but is an expression of intent today an adequate basis for ensuring that today's promises can and will be fulfilled tomorrow?

As I work for a national library, I am well aware of the costs of preserving printed publications, a cost which is necessarily met by the government. The printed archive in the UK has been built up through government intervention both to enact legal deposit laws, requiring a copy of every book and journal published in the UK to be deposited at the British Library, and by funding the Library appropriately for this purpose. It has also recognized the need to enact a new law to extend the Legal Deposit provisions to non-print publications, but this will take some years. Meantime, the Legal Deposit libraries and publishers in Britain are working together to introduce a voluntary deposit scheme. If successful, this will be a contribution to maintaining the record of science, but it cannot solve the international dimension.

As for print, a comprehensive scientific digital archive is likely to be complex and the result of disciplined, specific, institutional national and international initiatives. ICSTI believes that much more needs to be done to define archiving policies, to be clear about where responsibilities lie and to ensure that a properly supported infrastructure is in place which can stand the test of time. Commercial interests may keep many publications available for a period, but it is unlikely that they can sustain a permanent archive. That is why ICSTI believes that the issue of digital archiving is at root a matter of scientific and public policy. Scientists, publishers, librarians and information bodies, by working together, can do much to decide what needs to be done, and how it should be done. But there will be a cost to building and maintaining a comprehensive archive of science. That is why ICSTI is seeking to strengthen the recommendations emerging from the World Conference on Science to engage funding agencies and governments in contributing to this issue, which we believe is critical to ensuring access to information, now and in the future.

Note

1. The ICSTI Report on Digital Archiving is available at ICSTI's website: http://www.icsti.org

Thematic meeting report

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The theme of this meeting is certainly one which merits the attention of both the scientific community and funding organizations, as well as the recipients and users of new knowledge: industry, health care providers, governments.

The meeting, attended by around 100 persons, clearly demonstrated a widespread commitment to the development of electronic communication technologies for the dissemination of scientific information. Meeting presentations and discussion focused mainly on mechanisms and means for the sharing of knowledge between scientists. It was repeatedly stressed that the new technologies should be applied and managed in a way that benefits the scientific endeavour and distributes new research results – scientific knowledge – efficiently and fairly to all scientists worldwide.

The predominant vehicle for dissemination of new research results has been the scientific journal. The journal system – defined as print on paper – has, following the advent of the Internet, for some time been under intense pressure and is gradually breaking down. This system has, in principle, served science well but scientists in developing countries have presented well-argued criticisms. Expensive subscription fees, first world dominance in science publishing, language preferences and lack of attention to their own journals are problem areas that have often been cited.

New technologies not only provide alternatives for sharing scientific knowledge. They also – as was very much at the centre of meeting discussions – offer new possibilities for increased intellectual exchange between scientists and for efficient and speedy distribution of research results. These opportunities should not be missed.

What to share

So what is this 'scientific knowledge' which should be shared? It covers, of course, new research results, but also data, collected for study and for various forms of use: engineering, biodiversity studies, meteorology, etc.

Data made available electronically must therefore meet certain standards and data quality may become a problem in the Internet era. There are obvious risks with data floating around in cyberspace outside the control of the generator/collector, which makes documentation particularly important.

Data must also be usable. The myriad of computer systems, file formats, data representations and metadata standards could create a new Tower of Babel and solutions are being sought. Preservation and archiving of data is another issue of paramount importance. This is an area where much remains to be done.

The scientific journal plays a central role in the certification and communication of knowledge. It contributes to the quality of science through peer review and helps to establish the priority of ideas, protect the intellectual property of researchers, maintain the record of scientific progress over time and promote recognition and stature in a scientist's professional field. A universally accepted cluster of norms and practices has developed in connection with scientific communication and journal publication. The scientific community must now assess whether the norms and practices associated with traditional print publication are appropriate and functional in an increasingly electronic environment.

Some of these normative issues (e.g. the definition of a publication, citation practices and the peer review procedure) are of global and technical relevance and they apply irrespective of where, by whom and for which audience science is being published.

Digital publication facilitates the production and preservation of several versions of a scientific paper and it is therefore urgently necessary to establish norms for dealing with and distinguishing between communications in the forms of initial postings, referred versions, corrected or extended versions, etc. The possible existence of multiple versions of a scientific paper could result in confusion with regard to citation and referencing. Norms for citing such versions must be agreed upon. It is, however, equally important to secure that a cited work does not disappear from the digitalized world.

Peer review is not perfect as a quality filter for science publishing and several studies have pointed at procedural and other shortcomings. Discussion in Budapest – as elsewhere – concluded with agreement that it is the best mechanism so far established for quality control. It was stressed that peer review is a responsibility and a resource for both authors and publishers. Considerations for improving the quality and integrity of the review procedure should be part of in-depth studies of the new publishing paradigm.

How to share

The new technologies allow for faster and wider distribution of research results in quantities and formats previously unknown. New forms of interaction between author and reader will become possible, significantly affecting scientific work and bringing scientists worldwide closer to each other. This is an uncontested gain for science and offers particularly interesting new opportunities for improving the North-South and South-South knowledge-sharing process. It is extremely important that this favourable junction is explored in all its aspects in order to create for the international scientific enterprise a new knowledge-sharing environment based on fairness and equality.

The flow of scientific information is, however, not unhindered. Financial, technical and legal obstacles can create barriers, the heights of which differ greatly between various parts of the world.

The financial strength required to set up, maintain and run national network resources and keep them connected to the international ones is a great problem, especially for developing nations. This applies equally to access to training opportunities necessary in order to make optimum use of the facilities. Actors at all levels – international organizations, governments, non-governmental organizations, universities and individual scientists – must join forces to combat these problems. Much is already being done, but the extremely fast development calls for intensified action. The new technologies are costly and national research budgeting and international aid programmes should clearly take this into account.

The underlying legal framework also limits freedom of access to scientific information. Appropriate legal norms, nationally enacted and agreed upon in international conventions, which protect the author/inventor, can sometimes result in denial of access. This goes against well-established principles of full and open access to scientific data which have to date been considered part of a generally accepted code that has been highly advantageous to science.

New trends that provide the author/inventor and the publisher with stronger copyright protection are putting this principle at risk to the detriment of access and hence to the free conduct of science. The position of the database generator/owner has been greatly strengthened in new legislation and much that in the past was freely accessible in the public domain will be available only for a fee. A fair and science-friendly balance between the competing interests – protection for the investor/owner and freedom for the scientific community – must be found. This applies to scientific activities in general, but not least to science in developing countries.

Why share?

There does not really seem be any serious 'why' question. Science can only thrive and develop if it is allowed as an uncensored activity, fully open to critique and review by equals in a free, borderless international republic of science. But political, economic and cultural structures at the international and national levels can often result in inequality, which is contrary to the principles upon which international scientific cooperation and interchange – i.e. sharing of scientific knowledge – are based. Race, language, sex, creed and political affiliation still exclude individuals from participating fully and freely in scientific activities. In addition, and perhaps more importantly, financial problems bar many scientists from pursuing worthwhile scientific projects and engaging in international programmes. The effects of this are especially damaging for science in developing countries. Any conceivable hindrances for the free conduct of science anywhere and at any time should be firmly opposed and strong efforts should be made to achieve a better world order for science with improved mechanisms for knowledge sharing.

Recommendations

The meeting agreed to draw the particular attention of national World Conference on Science delegations to the following:

- the need to ensure that national and international law do not impede the flow of scientific information;
- the need for the costs of exploiting the opportunities inherent in the new technologies to be included in the funding of research.

The meeting also proposed additions and amendments to the drafts of the *Declaration on Science and the Use of Scientific Knowledge* and the *Science Agenda – Framework for Action* documents, as follows:

Declaration

- Full and open access to information and data belonging to the public domain (para. 16).
- Striking a reasonable balance between protection of intellectual property rights and allowing the scientific community access on fair conditions (para. 38).

Framework for Action

- The imminent need for action to preserve digitalized data (para. 21).
- (Same issue as second item in *Declaration*).
- Research funding should also cover costs of dissemination and sharing of knowledge (para. 21).

Science education for development: case study of Project 2000+, ELSSA

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It is now a truism that the world has approximated to what scientifically literate people call a global village. In discussing the theme Science Education for Development in this World Conference on Science, that notion of globalization must be brought to the fore. While this audience would not want to be bored with the long argument about science education as an academic discipline, there is, however, a need to draw attention to a global view of development, which oftentimes is confused with growth. While growth is a purely economic term simply meaning ‘more output of goods and services in a nation’, development, on the other hand, is a socio-economic term. It is a kind of socio-cultural change in which new ideas are introduced into a social system in order to produce higher per capita incomes and a ‘higher standard of living through modern science and technology’. With the involvement of science and science education worldwide, development could therefore be perceived as progress in desired directions which includes improvements in the material welfare of a people as well as the eradication of mass poverty, illiteracy and diseases. Who then determines development?

In the much talked about 21st century, scientific and technological innovations, along with the risks involved, will definitely take a gigantic stride. The role of science education, a vehicle by which scientific information is communicated to any society, will become most prominent in the global village. With well-coordinated science education as a powerful tool, selectivity of scientific information to suit different levels and classes of people in societies can be achieved. Unless scientific information is well dispersed, the development in one part of the global village can be lopsided and this can constitute the lack of development (underdevelopment) of another part of the same global village. Through science education, therefore, the strong link between science, technology and society (STS) can be demonstrated in order for them to bear on personal, institutional, community, national and world development. Particularly in the developing countries, specific audiences must be targeted through proper science education programmes. Children of this century, who will constitute the better part of the 21st century population, must be exposed to innovative, challenging and pragmatic science education programmes. As part of this discourse, we would therefore like to showcase a Project 2000+ science education programme, ELSSA, in a developing country which aspires to march into the 21st century with a cohort of a scientifically literate population.

Science education in schools

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As the world prepares for the 21st century, this workshop provides a precious opportunity for us, scientists and science/technology educators, to reflect on the role of science and science/technology education well as on the international action needed both to make full use of all opportunities offered by science and technology for development and to identify future trends and resources in this field in the early years of the new century.

Assessing the problem

Even in the middle of the current century, science education, which sometimes existed at the primary school level and took the form of separate courses in the basic sciences at the secondary level, was usually taught in a ‘bookish’ manner, without familiarizing students with the process of science and problem-solving techniques. Technology education was essentially absent from general education.

Later on, the idea of developing integrated science teaching started to take force and awareness of the impact of human interaction with the natural environment was emphasized. The rationale for this innovation some 20 years back was at least twofold. First of all, even at the secondary level, the academic programmes of students who were not preparing for scientific careers often did not include courses in the individual basic sciences. Secondly, and more importantly, the world of nature is experienced in a 'holistic' manner and not in terms of the 'disciplines', which are the product of centuries of specialization by scientists.

As regards technology, as there were essentially no equivalent starting points upon which to build, several options have been chosen to deal with secondary schools. A first option is to add technological aspects to the various science curricula. A second option is to develop science, technology and society courses to replace or be added to science courses. The last option is to introduce a new subject 'technology' into the secondary curriculum.

Today, we are aware of the increasing lack of interest in sciences among young people and we know that scientists are not happy with the way science is being taught in schools. Recent research has revealed several causes for this phenomenon. For example:

- the absence of a socio-cultural and economic dimension to the teaching of science and technology;
- the trend towards a science and technology education aimed principally at scientists and technologists, instead of the general public;
- the lack of ownership by science and technology educators, who have very little say in the planning and preparation of teaching materials or in the development of teaching methodologies;
- an exam-oriented science and technology education;
- the teaching of science and technology in a passive/inactive manner, inhibiting creativity, active participation and decision-making in students.

Towards a global response

The need to promote a world community of scientifically and technologically literate citizens was recognized as being urgent by the World Conference on Education for All (Jomtien, Thailand, 5-9 March 1990). As follow-up, Project 2000+: Enhancing Scientific and Technological Literacy for All, a collaborative venture based on a partnership between a group of major intergovernmental and non-governmental organizations, was launched by UNESCO in 1993 to promote and guide the measures needed to give effect to the *World Declaration on Education for All*, to bring about a more thorough infusion of scientific and technological culture into society.

Project 2000+ is based on the philosophy that science and technology increasingly affect our everyday world. Scientific and technological literacy (STL) thus play a crucial role in ensuring an economically and environmentally sound development of countries. Scientific and technological literacy for all is operationalized based on four educational pillars, namely:

1. personal development through acquisition of scientific knowledge;
2. personal mental development through use of scientific skills/methods;
3. development of individual attributes, attitudes and perceptions;
4. development of values and skills as a responsible member of society.

STL is based on the rationale that science education is seen as 'relevant in the eyes of the learner'. This should be the underlying basis for the learning of science and technology at all levels, which differs in perception (although not necessarily in content/context) from the current emphasis on science education as 'science learning considered important by scientists'.

Project 2000+ aspires to promote scientific and technological literacy for all by calling upon governmental and non-governmental organizations to take steps to put into place, by 2001, appropriate structures and activities to foster scientific and technological literacy for all in all countries.

The project builds on trends and developments in science and technology education over approximately the past 20 years and makes an attempt, within formal education, to bring together the considerable and growing research outcomes with the needs of curriculum developers, those monitoring the implementation process in schools, teacher educators and the teachers themselves.

In the above context, new trends and orientations of science and technology education are being promoted around the world, notably by the Project 2000+, e.g. integrated science; science and technology education for future human needs; science and technology in society (STS or SATIS), etc. At the philosophical level, worthy of mention are the perspective of 'science for all', 'constructive practices', 'interdisciplinary and holistic teaching', etc.

Basis of the strategy

It should be clear that STL is science education to meet the goals of education in a relevant and interesting manner. It sets about preparing citizens for life within society, both for the present and the future. The goal of science education is thus to enable students to reach a high degree of literacy with respect to the goals of education within a country or a system through science. The literacy component of STL is the society focus; the structures: science education. The aim is to motivate the students by providing education of greater relevance. For relevance in the eyes of the students, we need to consider science curricula, teaching and assessment. There are two ways this could be operationalized.

Teaching for greater student relevance

This is seen as a major teaching change for science education. Teachers have perceived science teaching to be about conceptual understanding/knowledge, maybe attitudes to learning/learning of science and rarely about using science for decision-making and the solving of problems in society.

For teachers to acquire new direction and embrace STL, there is a need to rethink their roles as science teachers. As a start, questions could be raised as to whether they should consider themselves scientists or educationalists who educate students through science.

Change of teaching approach

For classroom change to take place, the most important factor is the vision of science teaching by teachers themselves. Changes in science teaching can be based on the following:

- curricula based on science fundamentals (grouping science concepts for scientific convenience is not the approach to promote STL);
- teaching from a relevant societal context;
- teaching science concepts on a ‘need-to-know’ basis;
- teaching with attention to scientific methods (science processes);
- stressing educational goals (intellectual, personal, societal and communication).

Evidence suggests that teachers try to avoid change. There is thus an urgent need to convince teachers to embrace change. Two factors are of special significance.

1. Research evidence shows that change can lead to substantial gains by students and, very importantly, that students do not suffer in their ability to pursue science courses at a higher level (incidentally, such evidence is also needed to convince university science faculty staff, who are often the most sceptical of school science curriculum development).
2. It is necessary to provide suitable professional development courses for teachers as follows:
   - one approach which shows signs of success is to encourage teachers to reflect on the changing needs of science education and then, with this in mind, to develop supplementary teaching materials that meet this need;
   - teacher workshops which pay great attention to the philosophy of STL;
   - teachers creating supplementary materials which meet STL criteria.

The goal is to give ownership of the STL philosophy being expounded.

What elements for the strategy?

Efforts should concentrate on improving those aspects that have a bearing on the quality and relevance of science and technology education, as well as on people’s quality of life and the environment as a whole. In this context, the following could be mentioned:

- Popularization of science: the need to make science education more relevant to the needs and aspirations of students. In particular, the need for science education to be both an intellectual challenge for students and also an opportunity to relate science to society in a meaningful manner.
- Broadening the scope: the need to place more emphasis on key societal issues such as health, energy, food, environment, poverty, etc., as dimensions in an integrated/interdisciplinary approach.
- Science for all: the importance of relevant science teaching for all students, including gender equality, at all age levels. Science for all has as its goal the development of scientifically and technologically literate citizens.
- Professional development of teachers: the importance of empowering and supporting teachers and involving them in the implementation of the above three measures, especially in developing countries and for disadvantaged and minority groups.
- International cooperation: the need to share and build on research and developments which make science and technology education more appropriate in providing a platform for the building-up of the scientific and technological needs of countries and their citizens.
- Non-formal education: the importance of complementing science and technology education initiated in schools and making provision for lifelong learning.

A word on UNESCO’s action via the Project 2000+

In response to the call for renovation in science and technology education (STE) as a consequence of the challenges raised by the rapid changes occurring in society and the world of work, UNESCO, through the Project 2000+, is promoting actions in relevant areas such as the following.

- training and capacity-building: developing training courses and workshops aimed at reinforcing national capacities, notably in curriculum planners, teacher-educators and teachers;
- renewal of curricula and programmes: supporting governments in updating their curricula in line with the latest contents, trends and innovations in STE, as well as with the context-specific matter;
- materials development: disseminating relevant teaching/learning materials (e.g. a new resource kit on STE) and stimulating countries to produce their own;
- exchange of information and experiences: disseminating relevant information and experiences as well as exemplary materials on the website and through the newsletter *Connect*;
- popularizing science and technology for all: promoting links between school-based STE programmes and community initiatives and organizing non-formal activities such as contests, fairs, festivals, exhibitions, camps, etc.

The underlying objectives are to promote:

- understanding of the nature of, and the need for, scientific and technological literacy in relation to local culture and values and to the social and economic needs and aspirations of each country and its peoples, and also in accord both with the general aims of education for the all-round development of human personality and with human rights and basic freedoms;
- identification of those issues concerning the applications of science and technology which are of special importance for personal, local and national development and their embodiment in educational programmes.

Lastly, allow me to say that we need to pay much more serious attention to the scientific and technological needs of society for the 21st century and the way intentions in education are to be implemented in practice. Primary and secondary science and technology education have the potential to promote in the younger generation the critical thinking abilities and sense of civic responsibility necessary for them to participate productively in society now and throughout life.

To achieve these goals, governmental support is crucial, notably in reviewing existing provisions for science and technology education at all levels, with the aim of giving appropriate attention to development and maintenance of teaching and learning programmes responsive to the needs of individuals and communities.

Using modern distance education to improve science education in developing countries

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We live in a changing society

Many government leaders, scholars and entrepreneurs from most countries have realized that human society is once again experiencing a great revolution. The Industrial Revolution 250 years ago, on the one hand, has helped some countries achieve industrialization, a market economy and urbanization, and thus made these countries become the societies of modernization. On the other hand, during this Revolution some other countries and nations which could not grasp that chance fell into colonies or semi-colonies, which had to fight for independence and development before setting out for modernization.

Now a new era in the development of human society is taking place. Although we have not fully known its nature and we do not know how to describe it exactly: whether to call it a 'post-industrialized society', 'the third wave', 'the information era' or 'the knowledge-based economy era', what we can do is just welcome this new era. Since information technology is the core or the symbol technology causing the coming revolution, we may call this era 'the information era'. According to the statistics there will be over 600 million people using the Internet by the year 2002, and 80% of the residents of industrialized countries will be connected to the Internet by 2007. That is to say, the most advanced parts of human society will be built on the Internet – the knowledge platform for fields involving economy, politics and culture, with super-speed circulation of information and a wide connection to the world. The developing countries as well as the developed countries are all confronted with opportunities and challenges. Either they jump onto the boat or they are washed away by the waves; there is no other choice.

Education will experience a revolution

In this knowledge-based economy era or information era, the indisputable conclusion is that human intelligence is the most precious treasure, and education is the basis of all. An information society entails learning, and lifelong learning, for survival and development. An opportunity for everyone to study is a fundamental right that should be guaranteed as a priority in a state where starvation has been eliminated.

While fundamental changes are under way in our society, education will also inevitably experience a revolution:

- education is becoming the foundation of a knowledge-based economy;
- society is asking for greater access to education at a higher level, particularly science education;
- a knowledge-based society is a lifelong learning society;
- fundamental changes in educational philosophies and methods induced by information technology (IT) are taking place;
- education processes will gradually shift from being teacher oriented to being student oriented;
- education needs more international exchanges and cooperation.

The precursor of this revolution is the intensive application of IT in education.

Opportunities and challenges in Chinese education

China is a developing country with the world's largest population and significantly unbalanced regional development. Its educational reform and development are facing both opportunities and challenges.

By 1998, the nine-year compulsory education programme had been extended to 73% of the population of China. The illiteracy rate among young and middle-aged people had fallen below 6%. It is predicted that, by 2000, 85% of the population of China will have universalized the nine-year compulsory education programme and that the illiteracy rate among the young and middle-aged will have dropped to below 5%.

At present in China, only 9.1% of the right age group can enter institutions of higher education, including adult education colleges. This figure is predicted to rise to 11% by 2000. Yet, a majority of Chinese youth cannot receive higher education, while in developed countries up to 50% of youth can. It is hard to step onto the platform of the information era without receiving education at the third stage (the tertiary stage).

In China, there is unbalanced development in different regions. The provinces failing to provide the nine-year compulsory education programme are mostly situated in the poverty-stricken areas in the mid-west and the boundary areas populated by ethnic minority groups, such as Yunnan, Guizhou, Gansu, Qinghai, Xinjiang, etc. Universities, especially those with advanced standards and better research capabilities, are mostly situated in coastal provinces in the south-east. There also exists a marked difference in faculty quality in universities at different levels. The mid-west is in a disadvantageous position in both quantity and quality of education. These regions are less developed economically and weaker in scientific research. In the circle constituted by economy, scientific research and education, only education can turn the circle from a negative feedback circle into a positive one.

In order to upgrade the quality and effectiveness of education, it is necessary to enlarge the number of the people to be educated and help people in less-developed areas get rid of poverty as soon as possible and catch up to the new era. Developing modern distance education to accelerate the development of education is a practical and promising alternative.

The Ministry of Education has decided in the 'Action Plan for Invigorating Education towards the 21st Century' that a modern distance education programme should be put into effect. In the next three years the central government will contribute a considerable amount of capital for this purpose and will draw capital and effort from regions, enterprises and individuals, so as to complete the construction of modern distance education.

Distance education using CERNET and VBI

In order to carry out the tasks of an intensive application of IT and of developing modern distance education, the China Education and Research Network (CERNET) Demonstration Project was formally launched in 1994, organized by the Ministry of Education and supported by the State Planning Commission. To date, CERNET has connected more than 70 Chinese cities and 400 universities and colleges across the nation. It has up to 500 000 network users and has special international lines connecting Germany, Hong Kong, the UK and the USA. CERNET will speed up to 155M and connect to more cities and schools in the future.

The China Education TV Station has set up the VBI Center which, on 13 October 1998, began its distance-educational satellite broadcast using digital compression technology. The VBI Center, using the equipment developed by Xi'an Jiao Tong University, can form a 'green information highway', which conforms well to China's present national context. It lays stress on providing basic education and technical training, especially for the remote ethnic minority residential areas and the poverty-stricken areas. With various resources, we hope to provide every valley with a set of such equipment in the near future.

Although this distance-education system is only a one-way video signal broadcast and feedback using telephone lines connecting to CERNET, it has the merit of low cost, since the television-ownership rate is quite high – 92 out of 100 households, including rural areas, in 1997. Considering the high cost and low coverage of computer networks, it is believed that satellite television education will play an important role for some time to come, especially in rural areas. However, with the development and dissemination of computer network technology like CERNET or satellite digital computer technology, distance education is heading towards the multimedia and interactive mode, which will radically impact the content and forms of education at various levels. With radio and television as its main carrier of information and with individual self-study combined with concentrated teaching as its main learning method, distance education will be transformed into modern distance education, with the assistance of multimedia technology and the computer network, combining independent individual study with interactive learning. Such transformation is the trend in development worldwide. China, being a developing country, should on the one hand carry on with active research to keep up with the trend and on the other hand seek a development pattern suitable to its national context.

Early stages and expectations

China's modern distance education is still in the early stages, but it has already achieved some short-term success.

The modern distance-education system will, by sharing its resources, provide more youths with opportunities for higher education and higher qualifications. For example, Hunan University in Hunan Province has been experimenting with enrolling 1 000 students in different cities of the province. These students will receive degree courses from the university through the distance-education system. Zhejiang University is going to follow suit in Zhejiang Province.

The network will, by sharing resources, provide better learning conditions for more students. For instance, under construction is the network for sharing books and reference materials among Chinese universities and colleges. Libraries of more than 200 major universities will be connected to one another and to both the China National Library and the library of the Chinese Academy of Science. The project is expected to be completed by 2000. In another case, Southeast University and the Nanjing Post and Telecommunications College in Jiangsu Province are going to cooperate with four colleges in the southern part of the province, enrolling students in the colleges' well-developed disciplines and cultivating talents that are urgently needed in that area.

The network system will provide teacher training, especially for teachers in primary and secondary schools or vocational colleges in less-developed areas. The Ministry of Education in 'Action Plans for Invigorating Education in the 21st Century' has decided to train 100 000 primary and secondary school teachers in the next three years. Distance education will play an important role in combining or establishing new training colleges.

The network system will provide a digital information airway for remote areas by launching the Green Education Information System and by using live transmission satellites and VBI technology. This will prove useful in promoting educational standards, reinforcing economic and cultural development and improving the overall quality of education.

The network system will enhance continuing education. Tsinghua University has been providing continuing education for large and medium-sized companies in disciplines where it has an advantage. It has established long-term cooperation with companies and gained experience from the cooperation. Shanghai Jiao Tong University has been cooperating with Baoshan Steel Company by cultivating high-level technological and management talents for the company.

The network system will promote research cooperation among universities. For example, the Modern Physics Research Center at Fudan University is among the first to set up a virtual research centre. Seven universities have initiated a China Science Cooperation Network, which has about 30 university members now. Putting selected university research achievements on the network has helped to turn the achievements into practical productive forces and established a closer link between China's university research and economic development.

The network system will improve the dissemination of scientific and social education, including education for pre-school children and senior citizens. Shanghai TV University has achieved great success in disseminating English education and computer technology among Shanghai citizens.

The network system will enhance reforms of higher education institutions. With the completion of the Tsinghua Campus Network, the mode of acquiring knowledge has changed for many students at Tsinghua University. Teachers too are beginning to think about future reforms of their educational philosophy and methods. What is more significant is that the campus network is quickening reforms in administrative structures of universities. Redundant working units and personnel are being laid off to increase efficiency. Using the network easily solves some long-disputed problems.

The examples mentioned above are only some sparks of change. It is hoped that they will start a prairie fire of development with help from various sources. The open-door policy should be upheld. Joint efforts are welcome, as are international cooperation and communication.

Developing countries like China, with a large population and unbalanced economic and cultural growth, are generally confronted with the dilemma that their educational resources are not adequate for educational development. Therefore, distance education has become a strategic choice for them in order to develop national education. China must seize the opportunity to enhance the development of its education. Hopefully, a lifelong learning system will be established gradually through distance education.

Thematic meeting report

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We face a changing world, appropriately symbolized by the advent of the year 2000, in which science literacy and confident access to the knowledge base will determine the fate of communities and nations. Ignorance of science, formerly hazardous, alienating and foolish, will in the future become imprisoning and suicidal.

The draft *Declaration on Science and the Use of Scientific Knowledge* sets forth the issues of science and the use of scientific knowledge at the end of the 20th century. It serves to challenge those of us devoted to science education by the passage:

‘Stressing that access to scientific knowledge is part of the right to education and the right to information belonging to all people; and that science education is essential for human development and for creating endogenous scientific capacity…’

Universal science education is a key to any hopes for a ‘new commitment of science for human welfare,’ which is the central theme of the *Declaration*.

Since the development of knowledge creates these many choices, it is the obligation of the scientific and technological community to accept a major responsibility for the advancement of science education. We call upon the international science community to accept the moral obligation to fully participate in radical improvement of science education at all levels for all students. Scientists must contribute some of their time to collaborating with teachers and educators on advancing universal science literacy.

We have divided our subject and our discussions into three themes: Theme I: Science education for development; Theme II: Science education in schools; Theme III: Science education for future scientists and engineers.

Theme I: Science education for development

Speaker: Sam Bajah (Nigeria)

Panellists: Jajah Koswara (Indonesia), Lauritz Holm-Nielsen (Denmark), Molly Teas (USA)

The big idea in Theme I, as articulated by the speaker, panellists and the audience, is that science education for development must focus on children and the issues that surround them. Local experiences are most effective, especially when applied using the ‘hands-on’ inquiry method of instruction. Science for survival and for life should be tempered with science for eventual economic and social development. We are facing a declining interest on the part of young people in all parts of the world. A common problem is the very poor or non-existent training of primary teachers in mathematics and science and it is here where attitudes towards science are often established. The economic and social status of teachers must be raised to attract the best students to teaching.

Informal education via museums, science centres, television, radio, books and lectures is an important adjunct to schools. Technology, wherever available, is a powerful support for education; computers, calculators, Internet access and distance learning were stressed. Also listed were ‘hands-on’ techniques, using the simplest of devices such as local plants and animals, soap, rulers, paper and scissors, cartoon books, songs and poems, etc.

Educational lessons based on these are widely available. Schools in developing countries should reach out to girls whose education, even at the primary level, is crucial to the progress of the community. Role models, special workshops and other devices should be used to attract girls to science.

It has been suggested that a Science Corps (like the Peace Corps) be organized to interface between sources of exemplary educational materials (e.g. off the Internet) and the classroom teacher. Corps members could be recruited from university teachers and students, engineers, nurses, i.e. people with some technical education.

The explosive pace of 21st century science and technology (S&T) requires, more than ever, a universal S&T literacy on the part of all citizens of the world community. The relevance of S&T to the futures of individuals, communities, nations and the planet must be a component of lifelong learning.

Underlining all our themes is the need for a much greater participation of scientists, in collaboration with teachers, in advancing science education. We must revive the ancient tradition of tithing – each scientist should devote 10% of his or her time to advancing science education, in their community. By their participation, they will serve to diminish the isolation of S&T from the community at large. Finally, the growing global connectivity will surely make the Internet a major resource for world collaboration in improving science education.

Theme II: Science education in schools

Speaker: Colin Power (UNESCO)

Panellists: Jack Holbrook (UK), Winston King (Barbados), Caroline McGrath (UK)

Many of the issues relevant to education in all nations, industrial and developing, were already discussed in Theme I.

There is a common problem of popular science illiteracy, which appears in New York and Calcutta, Paris and Nairobi. This is unacceptable in a world in which technology is changing human behaviour with implications, sooner rather than later, for all the inhabitants of the planet. Decisions on such global problems as environmental protection and population limits require popular consensus and hence, some level of scientific thinking. The problems are in the schools, but declining interest of youth for science and unhappiness of scientists with the current state of school science is endemic. Some problems are:

- Absence of a socio-cultural and economic dimension to the teaching of science in schools.
- Too often, S&T is designed for future scientists and engineers and not for future citizens.
- Teaching of science is too often prescribed by a bureaucracy remote from classrooms and designed to pass tests which are themselves irrelevant to true understanding.
- Outdated, passive teaching methods that ignore the progress in cognition science. The latter encourages an 'inquiry' method of teaching, in which the active participation of students is essential.
- Whereas progress in the the sciences has exposed deep connections between the core disciplines, science education is too often rooted in 19th century methodology, perpetuated by a system of poorly trained teachers, fearful parents, conservative school officials – thereby missing the dynamics, the power and the beauty of modern progress in physics (and astronomy), in modern chemistry and in the new molecular biology. Resistance to change in the educational system is awesome. Here again, scientists must get involved.

We need better-trained teachers, continuous professional development and international cooperation in optimizing curricula and deploying educational technology for optimal impact. To influence the schools, we must influence the teachers, parents, school officials, and legislators; in short, we must popularize science and the urgency of drastic educational reform. Ultimately, what is sought is a seamless science curriculum from pre-school through high school (ages 3 to 18 years), with continuing efforts at adult lifelong learning. Science education in the schools must prepare all children for life in the 21st century.

Theme III: Science education for future scientists and engineers

Speaker: Wei Yu (China)

Panellists: Flavio Fava de Moraes (Brazil), Berit Olsson (Sweden), Munthir Salah (Palestine)

We begin with the truism that 'knowledge is the most important factor in economic development'. The knowledge base, following worldwide experience, dating back to the origins of our science and technology tethered civilization, lies in the university. Industrial societies, coping with internal problems of immigration, poverty, environment and economic competition, rely primarily on universities to train future scientists – to train teachers and to create and disseminate new knowledge. These, in turn, create millions of new, knowledge-related jobs, improve health care and general quality of life for their citizens. Universities also enrich the cultural and contemplative aspects of life, fortify the arts, tend to the understanding of our history and the enfolding in our lives of the wisdom of the humanities. Finally, and perhaps least successfully, is the aspect of ethical and moral behaviour, which should build on the teaching of such concepts in the lower schools but, in fact, is rarely done.

In developing countries, 'the need to increase their capacity to use knowledge cannot be overstated'. It is a prerequisite for sustained economic growth and improved quality of life. In developing nations like China, Indonesia and India the revolution in information technology (IT) must be used to extend the ability to reach university students over vast geographic areas, with widely differing university quality.

Distance learning becomes an essential tool in the building of university quality. University education abroad is another feature of development with the negative aspects of brain drain. This can only be countered by having attractive positions for the returning student. A Swedish process (Sandwich) addresses this issue in an interesting way through a bilateral arrangement of offering periodic education and research experiences to residents of developing countries. The role of the Internet can again be crucial in providing support to universities and research institutions. It can reduce the geographic isolation of scientists who need good access to current developments around the world. Funds for young scientists to attend conferences or to participate in research at unique facilities is a positive support.

The failure of universities is not only in the area of ethics and morality, but also in the training of teachers for primary and secondary school. The encouragement of university scientists to be involved in schools and in the implementation of educational technology is essential.

Science is the most communal of human activities. The 21st century can bring humanity to a level of unimaginable fulfilment, but the ever-present dark sides of technology and the failure of universal education can produce many decades of menace from natural and man-made catastrophes. Knowing that what we propose is not enough, nevertheless we put our trust in universal education, where knowledge-based science is deployed with the wisdom of the humanities.

The environmental consequences of tropical deforestation

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At the close of the 20th century, there are approximately 35 000 million hectares of forest in the world. Of this total forest area, 2 000 million hectares are found in tropical regions (FAO, 1997).

Tropical forest offers a very wide range of highly valuable services. To illustrate this, the forest serves important watershed and climate control functions, especially in regulation of stream flows, by intercepting rainfall, absorbing the water into the underlying soil and gradually releasing it into the streams and rivers of its watershed. The forest absorbs albedo (reflectivity of the sun's rays) from the sun and stores a sizeable share of the world's carbon. Forests absorb atmospheric carbon and replenish the oxygen in the air we breathe. Tropical forests are the most important source of biodiversity on Earth. They are home to 70% of all the Earth's species (Roper and Roberts, 1999). Industrial wood products account for US$ 400 billion worth of global production. Tropical forests account for approximately 25% of this production (WCFSD, 1998). Undisturbed tropical forests furnish essential foods, clothing and implements for indigenous forest people.

Deforestation is the permanent loss of forest to other land uses such as agriculture, grazing, new settlements, infrastructure and dam reservoirs (WCFSD, 1998). At the present time, 14-16 million hectares of tropical forests are being converted to other land uses, mostly agricultural. The Food and Agriculture Organization of the United Nations (FAO, 1997) has estimated the annual rates of deforestation in developing countries at 15.5 million hectares for the period 1980-90 and 13.7 million hectares for 1990-95. The total forest area lost during this 15-year period was approximately 200 million hectares. The tragedy lies in the fact that most of these deforested lands are not suited to long-term farming or grazing and quickly degrade once the forest has been cut and burnt (Roper and Roberts, 1999).

The principal agents of deforestation – those individuals who are cutting down the forests – include slash-and-burn farmers, commercial farmers, cattle ranchers, livestock herders, loggers, commercial tree planters, firewood collectors, mining and petroleum industrialists, land settlement planners and infrastructure developers.

The predisposing conditions that favour deforestation include poverty, greed, quest for power, population growth and illiteracy. The indirect causes of deforestation include inappropriate government policies, land hunger, national and global market forces, the undervaluation of natural forests, weak governmental institutions and social factors. The more visible direct causes of deforestation include the land uses that compete with the natural forests (e.g. agriculture, ranching, infrastructure development, mining and petroleum exploration). Logging, fuelwood collection and tree plantations also play a role in the deforestation phenomenon.

In some cases, deforestation can be beneficial. Given the right mix of social needs, economic opportunities and environmental conditions, it can be a rational conversion from one type of land use to a more productive one (Roper and Roberts, 1999).

The economic and environmental consequences of deforestation are profound, making it one of the most critical issues facing our global society. In economic terms, the tropical forest destroyed each year represents a loss in forest capital valued at US$ 45 billion (WCFSD, 1998). Tropical deforestation is a major component of the carbon cycle and has profound implications for biological diversity. Deforestation increases atmospheric CO_2 and other trace gases, possibly affecting climate (Bruce *et al.*, 1999). Conversion of forests to cropland and pasture results in a net flux of carbon to the atmosphere because the concentration of carbon in forests is higher than that in the agricultural areas that replace them. The paucity of data on tropical deforestation limits our understanding of the carbon cycle and possible climate change (IPCC, 1998). Probably the most serious and most short-sighted consequence of deforestation is the loss of biodiversity. Deforestation affects biological diversity in three ways: destruction of habitat, isolation of fragments of formerly contiguous habitat and edge effects within a boundary zone between forest and deforested areas. This boundary zone extends some distance into the remaining forest. In this zone there is greater exposure to winds; dramatic micro-meteorological differences over short distances; easier access for livestock, other non-forest animals and hunters; and a range of other biological and physical effects. The result is a net loss of plant and animal species in the edge areas (Roper and Roberts, 1999). The long-term impact of deforestation on the soil resource can be severe. Clearing the vegetative cover for slash-and-burn farming exposes the soil to the intensity of the tropical sun and torrential rains. This can negatively affect the soil by increasing its compaction, reducing its organic material, leaching out its few available nutrients and increasing the aluminium toxicity of soils, making it marginal for farming. In many cases, political decision-makers knowingly permit deforestation to continue because it acts as a social and economic safety valve.

While it is impossible to stop deforestation in the foreseeable future, there are many opportunities for bringing it under control and minimizing its negative impacts. Alternatives include the protection and management of remaining forests, socio-economic development in rural areas and policy and institutional reforms.

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Human-induced changes in the global nitrogen cycle: implications for coastal ecosystems

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Human alterations of the nitrogen cycle

The nitrogen cycle is one of the most important biogeochemical cycles on Earth, playing a major role in limiting the rate of organic production in the biosphere. Nitrogen (N) as N_2 is plentiful in the atmosphere, but only a small part of this N is made available to the biota through oxidation by lightning or incorporation by specialized microbes. However, during the last half of the 20th century human activities have resulted in approximately doubling the rate of production of biologically available, 'fixed' nitrogen on a global basis (Vitousek *et al.*, 1997). This is the result of the increases in manufacture of chemical fertilizers to support the needs of agricultural production, combustion of fossil fuels that releases fixed nitrogen into the atmosphere, planting of nitrogen-fixing crops (legumes and rice) and mobilization of N from long-term biological storage pools. Globally, N-fixation associated with agriculture is over three times that from fossil fuel combustion (Galloway *et al.*, 1995).

Much of the increase in fixed nitrogen in the biosphere has occurred in developed nations in which there is intensive use of industrial fertilizers and large releases of nitrous and nitric oxides into the atmosphere that ultimately fall to the Earth's surface. There, the rate of fixed N input to the terrestrial N cycle has increased fivefold to twentyfold (Howarth *et al.*, 1996). The rapid increase in fixed N during the concluding century has greatly outpaced the rate of human population growth, release of CO_2, and deforestation (Vitousek *et al.*, 1997). Human population growth and changing patterns of consumption will continue to drive increases in fixed N input through expanded fertilizer use, growing waste streams associated with increased animal food production, greater human and industrial waste effluents, and increased nitrogen oxide emissions to the atmosphere from fossil fuel consumption, particularly in the developing world (Galloway *et al.*, 1995).

The consequences of this substantial human alteration of the global N cycle include not only the dramatic increase in the world's agricultural production but also:

- increased release of nitrous oxide (N_2O), a greenhouse gas;
- formation of photochemical smog and unhealthy levels of ozone in and around cities;
- acidification of soils, streams and lakes from the deposition of nitric acid from the atmosphere;
- losses in other soil nutrients, such as calcium and potassium, as a result of nitrogen enrichment and acidification;
- increases in the quantity of organic storage in some ecosystems, ranging from forests to the coastal ocean;
- loss of biodiversity, especially plants and microbes adapted to efficient use of nitrogen that are out-competed by faster growing species;

- increased transfer of bio-available N via rivers and the atmosphere to coastal waters where it stimulates plant growth.

Effects on coastal ecosystems

The increased inputs of N from land into estuaries, bays and continental shelf environments have resulted in major changes in these ecosystems as a result of increased organic production, or eutrophication (Nixon, 1995). Although other nutrients, particularly phosphate and silicate, may also stimulate marine plant production in brackish or tropical waters, N is the nutrient that generally limits plant growth in coastal marine waters. N inputs stimulate micro-algal (phytoplankton) blooms that decrease water clarity and may in some cases be directly harmful to humans and marine animals (Paerl and Whitall, 1999). The resulting decrease in light availability and increased growth of epiphytic algae results in the loss of sea grasses (Duarte, 1995) and coral reefs due to shading and overgrowth. Decomposition of the enhanced organic production consumes oxygen, particularly in bottom waters isolated from oxygen sources at the surface by the density stratification of water masses. Depletion or elimination of dissolved oxygen in bottom waters may result in the mass mortality of bottom-dwelling animals or otherwise make the affected environments uninhabitable (Diaz and Rosenberg, 1995). While moderate N enrichment of coastal waters may stimulate food chains leading to fishery species, the effects on fisheries may be catastrophic when vegetated habitats are lost and severe oxygen depletion occurs (Caddy, 1993).

Around the world, many small estuaries and coastal lagoons that receive waste additions and run-off from concentrated human populations or agriculture show signs of over-enrichment with N. Not only have such semi-enclosed bodies been affected, but also ecosystems of open continental shelf waters and large seas that receive substantial riverine inputs from agriculture or from dense human populations experience extensive and severe oxygen depletion of bottom waters and other signs of eutrophication. These ecosystems include the northwest shelf of the Black Sea (Tolmazin, 1985; Mee, 1992), into which the Danube and other eastern European rivers drain; the northern Adriatic Sea (Malone *et al.*, 1999), which receives the Po River discharge; the Baltic and North Seas (Jørgensen and Richardson, 1996; Jansson and Dahlberg, 1999); and the northern Gulf of Mexico off the Mississippi River (Rabalais *et al.*, 1996). The areas affected extend over tens of thousands of square kilometres.

Historical records and historical reconstructions from biological and chemical indicators laid down in bottom sediments show that, while cultural eutrophication began earlier, severe and extensive eutrophication of coastal environments is a phenomenon of the last half of the 20th century. This is consistent with the time-lines of Vitousek *et al.* (1997) and Galloway *et al.* (1995) for increases in fixed N production and, more specifically, the explosive increase in the application of artificial fertilizers. In the regions mentioned above, agriculture is the largest source of land-based N inputs, although atmospheric deposition (Paerl and Whitall, 1999) and sewage discharges may also be significant. Because of the growing use of industrial fertilizers and increased combustion of fossil fuels in the developing world, similar manifestations of eutrophication of coastal waters are anticipated beyond Europe and North America (Nixon, 1995).

Reversal of eutrophication

When the dimensions and consequences of coastal eutrophication became recognized in the 1980s, governments in several regions began to make commitments and take steps to reduce nutrient inputs, both N and phosphorus, into coastal waters. Examples include intergovernmental commitments to reduce controllable inputs of N and P into the Chesapeake Bay by 40% by 2000 (Boesch *et al.*, in press); national legislation in Denmark requiring the reduction of N inputs by 50% and P inputs by 80% by 1998 (Jørgensen and Richardson, 1996); and a ministerial declaration of Baltic Sea countries that the loads of both N and P should be reduced by half by 1995 (Jansson and Dahlberg, 1999). None of these goals has yet been met. In each case, significant reductions in point sources (industrial and municipal discharges) have been achieved and some improvements in ecosystem health have been observed. However, much less progress in reducing diffuse sources of N from agriculture or the atmosphere has yet been documented.

Efforts to reduce atmospheric emissions of nitrogen oxides have to this point been aimed at reducing ground-level ozone risks rather than N enrichment of terrestrial or aquatic ecosystems. Increasingly, these ecological effects will have to be taken into consideration in addition to human health risks. More efficient application of fertilizers in order to reduce losses from the fields and more effective treatment of animal wastes will also be required. Inevitably, though, significant amounts of N will escape even the most efficient agricultural operations. These losses will have to be intercepted by restored aquatic ecosystems, such as wetlands and riparian zones, that serve as sinks for fixed N, returning it to the atmosphere as non-reactive N_2. More effective agricultural nutrient management, better management of urban and suburban stormwater run-off and further reductions in nitrogen oxide emissions into the atmosphere, combined with aquatic and riparian restoration within catchments, can reduce diffuse-source N loadings to coastal systems by 50% without loss of agricultural production or significant economic dislocation.

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Global climate change and cycling of toxic metals

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My presentation explores the relationships between global climate change (GCC) and the cycling of toxic metals in the environment. Among other things, GCC is expected to result in:

- an increase in the amount of UV-B radiation reaching the Earth's surface;
- a change (increase) in temperature of the atmosphere and Earth's surface;
- a change in the hydrological regime, especially the incidence of catastrophic weather incidents such as floods, storms and droughts.

These changes will link GCC to the heavy metal cycle in many ways:

- For some metals (especially mercury), the ratio of emissions from industrial sources and natural processes (sources) is expected to change; GCC may also change the current deposition pattern and can result in further dispersion of already deposited toxic metals.
- Sites around the world are heavily contaminated with mercury (including abandoned gold and silver mines and chlor-alkali plant graveyards) and a change in climate may lead to increased exhalation of mercury from these so-called 'chemical time bombs'.
- Many natural and anthropogenic sources emit toxic metals in forms that can undergo photochemical reactions in the atmosphere. For instance, the removal of mercury from the atmosphere is driven by the formation of reactive Hg(II) species by direct and indirect photochemical processes which are temperature dependent. GCC can thus alter the current deposition pattern for atmospheric mercury in many parts of the world.
- Global climate change is expected to trigger an increase in rates of biogenic production and release of volatile metal compounds, especially the methylated compounds of mercury, arsenic, selenium and lead, which are more readily taken up by the biota.
- Increased remobilization of previously deposited pollutant metals may convert some areas (such the northeastern region of the USA) from being a sink to an area source of toxic metals.
- Bio-accumulation of toxic metals by fish is closely linked to production of dissolved organic carbon (DOC) and water temperature, and these habitat characteristics are strongly influenced by GCC.
- Extensive flooding of coastal and low-lying areas would exert a drastic influence on the mercury cycle by increasing the efficiency and rates of mercury methylation as well as

the levels in water, zooplankton, benthic invertebrates and fish in the newly formed bodies of water. The downstream effects of the flooded areas may expose a significant fraction of the rich fisheries resource of many coastal areas to risk of mercury contamination.

- In temperate lakes, changes in food chain structure and function tend to be non-linear, so that small changes due to climate may result in rapid and drastic changes in bio-accumulation rates.
- Tropical and arctic ecosystems are particularly sensitive to heavy metal pollution. Because of the unique features of the food web, top predators of tropical and arctic ecosystems are more vulnerable to heavy metals compared to temperate species and global warming can further exacerbate the exposure of the most sensitive organisms to toxic metal pollutants.

Human activities have changed the natural biogeochemical cycle of toxic metals in many ecosystems. Global climate change can increase the risk of exposure of many people to toxic metals by changing the forms as well as the remobilization and bio-accumulation rates of this class of pollutants.

The role of the oceans in global climate change

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This paper briefly summarizes a few of the popular main findings of the Joint Global Ocean Flux Study (JGOFS), a programme of ICSU through the International Geosphere-Biosphere Global Change Programme (IGBP) and the Scientific Committee on Oceanic Research (SCOR). It also highlights a few of many factors and unknowns involved in predicting future scenarios in the ocean.

One of the challenges facing oceanographers at the turn of the millennium is predicting the nature and consequences of global warming. The enormous heat capacity of the oceans and their huge capacity to store dissolved CO_2 are important characteristics. Understanding the role of the oceans is therefore central to predicting global change. Transport of CO_2 in the oceans is strongly influenced by the physical ‘solubility pump’ whereby the solubility of gases like CO_2 increases in sea water as it is cooled in winter at high latitudes. The prime site is in the arctic North Atlantic where Atlantic Deep Water is formed by convective sinking of the cool, denser water, taking with it newly dissolved atmospheric CO_2. This forms the basis of the deep ocean thermohaline circulation, which takes of the order of a thousand years to complete its slow conveyer belt circulation through the ocean basins and back up to the surface, sequestering CO_2 from the atmosphere for many centuries. An important point to note is that the physical pump is reversible; it absorbs CO_2 then eventually releases it again into the atmosphere when the water upwells. The thermohaline circulation has now been shown to have varied strongly (possibly even reversed) between the Ice Ages and interglacial periods. The changes in this circulation pattern have not happened gradually but suddenly, as if triggered at a threshold. This has profound implications for the storage of the anthropogenic CO_2 accumulating in the atmosphere.

The biological pump, based on sinking of organic matter produced by phytoplankton, depends on the physical environment and the supply of nutrients to the sunlit surface ocean. It is essentially a one-way process, sequestering carbon to the deep ocean and ocean floor. Until recently, nitrate was assumed to be the main limiting nutrient in the oceans but it has been convincingly shown that vast areas of the equatorial Pacific, the temperate northern Pacific and now the Southern Ocean are limited by the supply of trace amounts of iron, not nitrate. Large scale *in situ* iron fertilization experiments have now been conducted in both the equatorial Pacific and Southern Oceans, with dramatic and spectacular results. In both cases, fertilization with trace amounts of iron over several square kilometres has resulted in faster phytoplankton growth, with increased diatom biomass after several days, and uptake of both nitrate and CO_2. It is suggested that many coastal areas and ocean areas downwind of deserts are not iron-limited because of the aeolian transport of iron in the dust blown off the land and into the oceans, e.g. the North Atlantic is largely fertilized by the Sahara Desert. Thus, the activity of the biological CO_2 pump may be strongly influenced by other elements, including trace elements, in a strongly non-linear fashion, making prediction very difficult. The situation becomes more complicated when one considers that the composition of biological communities of organisms is strongly influenced by small changes in their physical and chemical environment, and the species composition of plankton communities in turn determines the strength and activity of the biological pump.

Dimethyl sulphide (DMS) is the major naturally produced source of sulphur to the atmosphere. DMS produces aerosol particles which affect the radiative properties of stratus clouds, the Earth's albedo, with a strong cooling effect on climate, thus damping global warming. DMS production in turn depends on the composition of phytoplankton communities in surface waters, which is sensitive to their environment. Climate models which include aerosols have performed better than those that do not, in that they mimic the data better than the versions which exclude aerosols.

Overall, we are still some way from understanding the non-linearities of either the physical or biological CO_2 pumps and therefore from modelling future scenarios with confidence. Nevertheless, in the last 10 years we have come a long way in understanding the processes underlying the operation of the physical and biological pumps. We still do not know the details of the thresholds involved in turning the deep ocean circulation on and off, with profound implications for climate, both directly in distributing heat and CO_2, and indirectly via species changes which control the biological pump.

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Water resources for human use: a perspective in view of climate variability impacts

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Water promises to be the single most important issue in the coming century. It will engage development leaders, activists and critics all in the next decades. Of all the water that exists on Earth, only 2.5% is not sea or salt water, of which 0.3% is available in lakes and rivers. Therefore, as far as human use is concerned, less than 0.08 of 1% of all of the water on the planet is considered fresh water. The amount and distribution of fresh water in space and in time varies considerably on a global scale. Some regions experience an annual rainfall of over 2 000 millimetres, evenly distributed throughout the year, while others barely reach a few millimetres. However, a vast majority of countries frequently suffer from a distinct seasonal pattern, where precipitation reaches extremely high amounts during the wet season, while serious water shortages and droughts may occur during the rest of the year. Anomalous precipitation patterns, in the form of extremely severe drought or excessive rainfall, are modulated by climate variability. Complex air-sea-land interaction processes regulate climate variability at different global scales. Climate variability is a natural phenomenon and humankind has to deal with it.

The negative impact of droughts or excess precipitation can be increased due to human activities. Anthropogenic processes put additional stress on water resources. Overpopulation, together with extensive agriculture, industrialization and soil erosion due to changes in land cover, are the major human-induced stress agents on water resources (Donoso and Bakkum, 1998). Consequently, a comprehensive integrated water management system is extremely difficult to develop and to implement on a global scale.

Sustainable water management for human use demands intersectoral and transboundary collaboration. But it all starts with a reliable assessment of our water resources. However, water management plans cannot be sustainable when the influence of climate variability is not taken into account. The complex structure of the air-sea-land interactions of water are not yet fully understood. In addition, long-term forecast skills, although considerably improved over the past few years, are still incapable of predicting the intensity of anomalous variations in climate with sufficient anticipation to allow society to take adequate measures to mitigate its effects. This situation adds complexity to the already difficult task of adequately managing water in most regions of the globe.

In the next century, a priority objective in science will be to acquire better understanding of the air-sea-land interactions that dominate climate variability on global and regional scales. The sometimes severe repercussions of these interactions stress the need for assessing their impacts while improving our knowledge of the complex mechanisms that control these physical processes. One of these interactive processes is El Niño (also known as El Niño – Southern

Oscillation, or ENSO), and its counterpart La Niña (also known as the cold ENSO phase). The present work focuses on the effect of El Niño and La Niña on water distribution and availability for human use, with especial emphasis on the 1997-98 El Niño event. Assessment is performed on the effects of climatic events on crucial economic sectors, such as health and agriculture.

The interaction of the world oceans with the overlying atmosphere modulates the global climate. However, anomalous sea surface temperatures (SST) in the equatorial Pacific exert a larger influence on the climate. Excessively warm SST in the eastern Pacific characterize El Niño, while anomalous cold SST define opposite climatic conditions known as La Niña or anti-Niño (Donoso *et al.*, 1994). An El Niño or warm episode alters the temperature or precipitation patterns more than a La Niña or cold episode.

In the Americas, El Niño brings excess precipitation, causing devastating flooding on the west coast of South America (Colombia, Ecuador, Peru). On the contrary, severe droughts take place over much of Central America and part of the Caribbean. Furthermore, in arid regions such as the northeast of Brazil, the already scarce water sources become insufficient to provide the minimum amounts needed for the everyday activities of a vast majority of the population. The linkage between these climatic effects and El Niño is now well established (Donoso and Cabrera, 1994).

During January-February 1998, tropical precipitation was greatly enhanced along the coast of the eastern equatorial Pacific. On the coasts of Ecuador and northern Peru, El Niño-enhanced rains persisted with six-week precipitation excesses of 390-740 millimetres across the region. During the two months of December 1997 and January 1998, the area received 350-775 millimetres of rain, compared with annual norms of 20-60 millimetres (WMO, 1998). Precipitation was suppressed in the southern Caribbean and northern South America. Very warm and dry conditions spread southward over the region. Six-week precipitation shortfalls of 100-250 millimetres were reported across western Colombia, French Guyana, Guyana, Surinam and most of western, central and east-central Brazil (WMO, 1998). This overall pattern of precipitation considerably affected the water resources of the hemisphere. El Niño continued to dominate climatic conditions into April 1998, causing extreme precipitation and severe storms in certain regions (e.g. Argentina), and exceptionally dry conditions in others (e.g. northeast Brazil). In other areas (e.g. Caribbean and Central America), its influence continued well into May-June 1998.

The effects of climate variability, and El Niño in particular, differ from one region to another. To assess the impact of changes in climate in a given area, two main questions need to be addressed: firstly, which are the socio-economic sectors most vulnerable to climate variability and, secondly, which of these sectors are of most importance to the region? Recent work carried out within the Trade Convergence Climate Complex (TCCC, 1996) study yielded that three of the major socio-economic sectors impacted by climate variability in the region are: health, agriculture and energy. These results are valid for the entire globe. Water is the linking element that dominates the activity of all three sectors. The abnormal precipitation regime experienced in the past El Niño event led to considerable changes in the distribution, quality and quantity of water that ultimately influenced to a different extent each of these sectors. El Niño 1997-98 will not be remembered as the strongest registered warm episode, but as the one with, by far, the most impact in modern history.

Agriculture is one of the socio-economic sectors that heavily depends on water. El Niño conditions, both floods and droughts, severely impacted agriculture. In Peru, countless harvests were ruined. The Ministry of Agriculture steered farmers away from storm-vulnerable crops like cotton, in order to soften El Niño's effect on agriculture. An estimated 42 738 hectares were reported lost and more than 75 500 hectares were damaged (*El Comercio*, 1998*b*), while in Ecuador El Niño damaged 152 865 hectares of farmland with rice being the main crop damaged, with a total loss of US$ 100 million. Also, as expected in this country, the production of cocoa decreased by more than 50% (*El Telégrafo*, 1997) and that of sugar declined by almost 60% (*El Universo*, 1997).

Furthermore, Cuba reported one of the worst sugar harvests in years. In Colombia, most rivers reached all-time lowest levels and river discharges dropped to 40% of the normal river discharges. The Colombian coffee industry was seriously affected by abnormal droughts; a decrease in the yield of more than 20% was reported. About 70 000 hectares needed to be replanted, 2.5 times the amount in a normal year (*El Nuevo Herald*, 1998). Rice production in Panama dropped in 1998 by almost 70% due to changing precipitation patterns (*Panama News*, 1998). This meant a loss of US$ 35 million. This affected the primary sector in Panama directly and almost immediately led to increased stress on the water resources available for human use, both in the cities and the rural areas.

Latin America depends for a significant part of its energy on hydroelectricity. El Niño-driven droughts caused hydropower installations to halt in various countries. In

Panama, the government carried out rationing of electricity during March and April. In Colombia, 5% of households did not have electricity for weeks because of this El Niño effect (*El Tiempo*, 1998). An electricity shortage was also experienced in Venezuela.

The 1997-98 El Niño event had a dramatic effect on the health of a vast majority of the population in the most significantly affected areas of the Americas. In Peru, because of the increased humidity, a strong increase in water-borne diseases was reported and the spectre of cholera and malaria epidemics threatened the population. Cholera increased for lack of potable water. In addition, in various places, when mud from the floods dried up, it created dust, which caused respiratory illness, allergies and other symptoms. The government made efforts to disinfect flooded areas in an attempt to prevent the generation and spread of disease. Also, pamphlets were distributed on how to avoid or cure conjunctivitis and other diseases. However, due to the huge territory affected by El Niño it was impossible to cover all areas (Reuters, 1998). By the end of April, the number of reported cases of various diseases was disturbing: 168 575 cases of acute diarrhoea; 7 868 cases of confirmed cholera and 6 767 of unconfirmed cholera; 238 561 cases of acute respiratory illness; 11 241 cases of pneumonia; 31 103 cases of malaria; and 304 cases of dengue (Donoso and Bakkum, 1998).

Furthermore, in Manaus, Brazil, an epidemic of dengue fever started in late March 1998. By 2 April, the Instituto de Medicina Tropical of Manaus had seen 240 cases. Cases of dengue fever were also reported in northern South America and Central America. On the Amazon side of Ecuador, malaria was widespread (*El Comercio*, 1998*a*). Efforts to control the spread of the disease were hampered by the poor road conditions and limited health facilities in the area.

In conclusion, El Niño 1997-98 ranks as one of the major climatic events of the 20th century, not just in terms of its intensity, but mostly in regard to its impact. The estimated cost of this event worldwide is expected to surpass the estimated amount of US$ 10 billion for the impact of the 1982-83 El Niño. In reality, these figures are much higher, owing to long-term effects of the disruption of local economies.

Consistent with the findings of the TCCC study, the most severely affected socio-economic sectors are agriculture, energy and health. Costs due to negative El Niño impacts on these sectors are estimated to be in the range of over two-thirds of the total damage costs expected in the region. The major financial institutions in the Americas were forced rapidly to develop emergency assistance projects. This operation aimed also to support measures to improve the governments' capacity to plan and manage future emergencies. However, efforts need to be undertaken within the countries to enhance awareness of, and preparedness for, climate-related anomalous developments.

Finally, the impact on water resources that took place as a result of the El Niño 1997-98 calls for a more permanent and efficient collaboration between decision- and policy-makers and the scientific community, in order to further understand and better mitigate the effects of climate variability. To accomplish this, adequate mechanisms have to be established to guarantee the constant and fluent transfer of quality information in both directions.

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Global problems related to biodiversity science, especially the effects of invasive species

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Public awareness about the accelerated loss of species on both the local and global scales has increased in the last decade and has crystallized in international consensus on the relevance of the subject. The most important such consensus is represented by the Convention on Biological Diversity (CBD) which, together with the Convention on Climate Change, has become a key component of the international agenda on global environmental issues, triggered by the 1992 Rio de Janeiro meeting (United Nations Conference on Environment and Development).

The CBD recognizes clearly that the conservation of biological diversity, as well as the factors that threaten it, are problems that transcend economic, political, religious and cultural frontiers. They also transcend the merely quantitative aspect of the loss of species belonging to many different taxonomic groups in a certain region, which in itself constitutes a very important issue. It expands both to a global-scale problem and to a variety of factors fundamental for maintaining life as we know it, for us and for the other organisms with which we share this planet.

All those factors are linked and dependent on the biological diversity which composes the variety of ecosystems of the world, either natural or man-made, often in ways which make them difficult to be understood and predictable. Additionally, the complexity of those factors is not limited to the realm of the biogeophysical sciences, but includes, in a very central way, intricate social issues.

Human activity is causing changes in the environment which, directly or indirectly, are causing the extinction of scores of species in both terrestrial and aquatic systems at a rate that, if it is maintained, will represent the most severe process of extinction in the recorded history of our planet since life developed on it. The most serious loss, besides that of taxa, is the loss of the multiple and fundamental services provided to mankind by the ecosystems formed by the complex interactions of those species. These processes of ecosystem loss are presented and discussed.

The second most important factor in the loss of biological diversity on a global scale is the accidental or purposeful introduction of exotic species which become aggressive and invasive in the new areas into which they are introduced, causing, besides the disappearance of populations and entire species, enormous economic hardship. The factors involved in this process are presented and discussed.

Thematic meeting report

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Some 100 participants attended the meeting. After the introduction to the session by the Chair, seven presentations were made which covered a wide range of environmental science issues.

In his presentation on the Environmental Consequences of Tropical Deforestation, Professor C. Cerri emphasized that, at the close of the 20th century, there are approximately 3 500 million hectares of forest in the world. Of this total forest area, 2 000 million hectares are found in tropical regions. The forest absorbs albedo (reflectivity of the sun’s rays) from the sun and stores a sizeable share of the world’s carbon. Forests absorb atmospheric carbon and replenish the oxygen in the air we breathe. Tropical forests are the most important source of biodiversity on Earth. They are home to 70% of all the Earth’s species. Industrial wood products in tropical regions account for US$ 100 billion worth of global production. Undisturbed tropical forests furnish essential foods, clothing and implements for indigenous forest people.

Deforestation is the permanent loss of forest to other land uses. At the present time, 14-16 million hectares of tropical forests are being converted to other land uses, mostly agricultural. The total forest area lost during the last 15-year period was approximately 200 million hectares. The tragedy lies in the fact that most of these deforested lands are not suited for long-term farming or grazing and they quickly degrade once the forest has been cut and burnt.

The principal agents of deforestation include: slash-and-burn farmers, commercial farmers, cattle ranchers, livestock herders, loggers, commercial tree planters, firewood collectors, mining and petroleum industrialists, land settlement planners, infrastructure developers. The predisposing conditions that favour deforestation include poverty, greed, quest for power, population growth and illiteracy. The indirect causes of deforestation include inappropriate government policies, land hunger, national and global market forces, the undervaluation of natural forests, weak government institutions and social factors. The more visible direct causes of deforestation include the land uses that compete with the natural forests. Logging, fuelwood collection and tree plantations also play a role in the deforestation phenomena. In some cases, deforestation can be beneficial. Given the right mix of social needs, economic opportunities and environmental conditions, it can be a rational conversion from one type of land use to a more productive one. The economic and environmental consequences of deforestation are profound, making it one of the most critical issues facing our global society. Deforestation increases atmospheric CO_2 and other trace gases, possibly affecting climate.

Probably the most serious and most short-sighted consequence of deforestation is the loss of biodiversity. The long-term impact of deforestation on the soil resource can be severe. Clearing the vegetative cover for slash-and-burn farming exposes the soil to the intensity of the tropical sun and torrential rains. This can negatively affect the soil by increasing its compaction, reducing its organic material, leaching out its few nutrients available, increasing the aluminium toxicity of soils, making it marginal for farming. In many cases, political decision-makers knowingly permit deforestation to continue because it acts as a social and economic safety valve.

Professor D.F. Boesch’s presentation on Human-induced Changes in the Global Nitrogen Cycle: Implications for Coastal Ecosystems revealed that, during the latter half of the 20th century, human activities have resulted in an approximate doubling of the rate of production of biologically available, ‘fixed’ nitrogen (N) on a global basis. This is the result of the increases in the manufacture of chemical fertilizers to support the needs of agricultural production, the combustion of fossil fuels that released fixed N into the atmosphere, the planting of N-fixing crops (legumes and rice) and the mobilization of N from long-term biological storage pools. Much of this has occurred in developed nations. The rapid increase in fixed N has greatly outpaced the rate of human population growth, release of CO_2 and deforestation.

The consequences of this substantial human alteration of the global N cycle include not only the dramatic increase in the world’s agricultural production but also: increased release of nitrous oxide (N_2O), a greenhouse gas; formation of photochemical smog; losses in other nutrients; acidification of soils, streams and lakes; increases in the quantity of organic storage in some ecosystems; loss of biodiversity, especially plants and microbes adapted to efficient use of nitrogen; and increased transfer of bio-available N via rivers and the atmosphere to coastal waters.

The increased loading of N to estuaries, bays and continental shelf environments has resulted in major changes to these ecosystems, including increased eutrophication and algal blooms. Not only have restricted estuaries and lagoons been affected, but ecosystems of open continental shelf waters that receive substantial riverine inputs from agricultural or heavily populated regions have been greatly altered since the 1950s. Based on the growing use of industrial fertilizers in the developing world, particularly South and East Asia, similar problems are anticipated. Through more efficient application of fertilizers and the restoration of aquatic ecosystems, N loadings to coastal systems can be halved without loss of agricultural production.

The presentation by Professor J.O. Nriagu on Global Climate Change and Cycling of Toxic Metals explored the relationships between global climate change (GCC) and the cycling of toxic metals in the environment. Among other things, GCC is expected to result in an increase in the amount of UV-B radiation reaching the Earth’s surface; a change (increase) in temperature of the atmosphere and the Earth’s surface; and a change in the hydrological regime, especially the incidence of catastrophic weather incidents such as floods, storms and droughts. These changes will link GCC to the heavy metal cycle in many ways.

The ratio of emissions from industrial sources and natural processes (sources) is expected to change. Sites around the world are heavily contaminated with mercury and a change in climate may lead to increased exhalation of mercury from these so-called ‘chemical time bombs’.

Many natural and anthropogenic sources emit toxic metals in forms that can undergo photochemical reactions in the atmosphere. GCC can thus alter the current deposition pattern for atmospheric mercury in many parts of the world. Global climate change is expected to trigger an increase in rates of biogenic production and release of volatile metal compounds, especially the methylated compounds of mercury, arsenic, selenium and lead which are more readily taken up by the biota. Bio-accumulation of toxic metals by fish is closely linked to production of dissolved organic carbon (DOC) and water temperature, and these habitat characteristics are strongly influenced by GCC. In temperate lakes, changes in food chain structure and function tend to be non-linear, so that small changes due to climate may result in rapid and drastic changes in bio-accumulation rates. Tropical and arctic ecosystems are particularly sensitive to heavy metal pollution.

Human activities have changed the natural biogeochemical cycle of toxic metals in many ecosystems.

Professor J.G. Field, in his talk on the Role of the Oceans in Global Climate Change, stated that one of the challenges facing oceanographers at the turn of the millennium is predicting the nature and consequences of global warming. The enormous heat capacity of the oceans and their huge capacity to store dissolved CO_2 are important characteristics. Understanding the role of the oceans is therefore central to predicting global change. Transport of CO_2 in the oceans is strongly influenced by the physical ‘solubility pump’ whereby the solubility of gases such as CO_2 increases in sea water as it is cooled in winter at high latitudes. The prime site is in the arctic North Atlantic where Atlantic Deep Water is formed by convective sinking of the cool, denser water, taking with it newly dissolved atmospheric CO_2. This forms the basis of the deep ocean thermohaline circulation, which takes of the order of a thousand years to complete its slow conveyer belt circulation through the ocean basins and back up to the surface, sequestering CO_2 from the atmosphere for many centuries. This has now been shown to have varied strongly (possibly even reversed) between the Ice Ages and interglacial periods. The changes in this circulation pattern have not happened gradually but suddenly, as if triggered at a threshold. This has profound implications for the storage of the anthropogenic CO_2 accumulating in the atmosphere. The biological pump, based on sinking of organic matter produced by phytoplankton, depends on the physical environment and the supply of nutrients to the sunlit surface ocean. Until recently, nitrate was assumed to be the main limiting nutrient in the oceans but it has been shown that vast areas of the equatorial Pacific, the temperature northern Pacific and now the Southern Ocean, are limited by the supply of trace amounts of iron, not nitrate. Many coastal areas and ocean areas downwind of deserts are not iron-limited because of the aeolian transport of iron in the dust blown off the land and into the oceans, e.g. the North Atlantic is largely fertilized by the Sahara Desert. Thus, the activity of the biological CO_2 pump may be strongly influenced by other elements, including trace elements, in a strongly non-linear fashion, making prediction very difficult. The situation becomes more complicated when one considers that the composition of biological communities of organisms is strongly influenced by small changes in their physical and chemical environment.

Dr M.C. Donoso, in her presentation on Water Resources for Human Use: a Perspective in View of Climate Variability Impacts, highlighted that water promises to be the single most important issue in the coming century. Of all the water that exists on Earth, only 2.5% is not sea or salt water, of which 0.3% is available in lakes and rivers. Therefore, as far as human use is concerned, less than 0.08 of 1% of all of the water on the planet is considered fresh water. The amount and distribution of fresh water in space and in time varies considerably on a global scale.

Some regions experience an annual rainfall of over 2 000 millimetres, evenly distributed throughout the year, while others barely reach a few millimetres. However, a vast majority of countries frequently suffer from a distinct seasonal pattern, where precipitation reaches extremely high amounts during the wet season, yet serious water shortages and droughts may occur during the rest of the year. Anomalous precipitation patterns, in the form of excessive rainfall, are modulated by climate variability. Complex air-sea-land interaction processes regulate climate variability on different global scales. Climate variability is a natural phenomenon and humankind has to deal with it. The negative impact of droughts or excess precipitation can be increased due to human activities. Anthropogenic processes put additional stress on water resources. Overpopulation, together with extensive agriculture, industrialization and soil erosion due to changes in land cover, are the major human-induced stress agents on water resources in the region. Consequently, a comprehensive integrated water management system is extremely difficult to develop and to implement on a global scale.

A priority objective is to acquire better understanding of the air-sea-land interactions that dominate climate variability on global and regional scales. The sometimes severe repercussions of these interactions stress the need for assessing their impacts while improving our knowledge of the complex mechanisms that control these physical processes. One of these interactive processes is El Niño (also known as El Niño – Southern Oscillation, or ENSO), and its counterpart La Niña (also known as the cold ENSO phase). Assessment was performed on the effects of these climatic events on crucial economic sectors, such as health, agriculture, energy and others. Water is the linking element that dominates the activity of all these sectors.

In the last presentation, Professor J. Sarukhan outlined Global Problems Related to Biodiversity Science, especially the Effects of Invasive Species and recalled that public awareness about the accelerated loss of species on both local and global scales has increased in the last decade. The most important consensus is represented by the Convention on Biodiversity (CBD) which, together with the Convention on Climate Change, has become a key component of the international agenda on global environmental issues triggered by the 1992 United Nations Conference on Environment and Development held in Rio de Janeiro (Brazil).

The CBD recognizes clearly that the conservation of biodiversity, as well as the factors that threaten it, are problems that transcend economic, political, religious and cultural frontiers. They also transcend the merely quantitative aspect of the loss of species belonging to many different taxonomic groups in a certain region, which in itself constitutes a very important issue. It expands both to a global-scale problem and to a variety of factors fundamental for maintaining life.

All those factors are linked and dependent on the biological diversity which composes the variety of ecosystems of the world, either natural or man-made, often in ways which make them difficult to understand and predict. Additionally, the complexity of those factors is not limited to the realm of the biogeophysical sciences, but includes, in a very central way, intricate social issues. Human activities are causing changes in the environment which, directly or indirectly are causing the extinction of scores of species in both terrestrial and aquatic systems at a rate that, if it is maintained, will represent the most severe process of extinction in the recorded history of our planet since life developed on it. The most serious loss, besides that of taxa, is the loss of the multiple and fundamental services, which the ecosystems formed by the complex interactions of those species, provide to mankind.

The second most important factor in the loss of biological diversity on a global scale is the accidental or purposeful introduction of exotic species which become aggressive and invasive in the areas into which they are introduced, causing, besides the disappearance of populations and entire species, enormous economic hardship.

After the presentations a lively discussion took place. There was consensus that the gap between the natural sciences and social sciences as applied to environmental problems needs to be closed if environmental sciences are to be policy-relevant. The participants emphasized the need for interdisciplinary approaches both to enhance the knowledge base and to connect to the driving processes. Several participants proposed assigning a new momentum to build up outreach programmes for the widest possible audience ranging from the general public, through journalists and up to policy-makers and the political community. They urged UNESCO to assist in developing comprehensive environmental education programmes. Downscaling of the various global processes to regional level was considered as a very important challenge, in order to identify future possible hot spots in the context of global change. Water-related issues have been recognized as an important environmental challenge for the 21st century.

The discussion could be grouped according to the following issues:

- The major environmental issues of our time are linked in various ways and so must be studied in the context of each other.
- To be policy-relevant, environmental assessments must contain a socio-economic component.
- Environmental assessments must work across scales in space and time. Regional assessments on decadal time-scales are particularly important.

The meeting suggested that an early task should be the development of a Vision for the Environment for the 21st Century that should be implemented through a very wide consultation process with all the stakeholders involved. As environment will likely become a security issue, this Vision could be used to identify the proper response strategies in order to mitigate the relevant risks.

The biological revolution and its implications for health: an overview

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The new millennium finds us in the midst of a biological revolution driven by the explosive advances of genetics and molecular biology of the last half century. This revolution has given mankind the power to alter the course of evolution and to mould the stuff of life. The whole sequence of the human genome is only a few months away and the deluge of information about genes, proteins and their interactions is beyond the grasp of the human mind.

This revolution entails a change in the way we will have to conduct research and in the way we interpret the results of that research, since it will be necessary to address the immense complexity of the whole living cell or of a complete organism to draw valid conclusions as to the function of each molecular component of the life process. These changes require also a new way of training our students, giving emphasis to integrative capacities and to a broader knowledge that can find correlations and patterns within the incredibly complex circuitries of the cellular metabolic pathways.

As scientists, we are convinced that knowledge is good and that the post-genomic era of biology will result in a much more profound understanding of the fascinating mysteries of the phenomenon of life, of our own nature and of our cognitive capacities. The benefits of this knowledge and understanding should be specially evident in medicine, where the genetic basis of many diseases will become clear and where new therapies for old and new maladies will bring relief from suffering to millions of individuals. The genomics of micro-organisms will give us new tools to combat old or emerging infectious agents and pharmacogenomics will lead to the design of drugs tailor-made for the genetic characteristics of each patient. The knowledge of the genetic health risk factors of individuals at birth should result in careful monitoring and more efficient medical treatments.

This hopeful and optimistic picture, however, is darkened by the fact that the benefits of science and technology, especially those in the biomedical area, will not reach all of humankind. The millions of poor in the developing world will continue to suffer the devastating effects of diseases for which science will have found cures unless we, scientists and political leaders, do something drastic. An effort has to be made to stimulate health research in the developing world and to direct the enormous global scientific capacity to focus on the illnesses that attack the vast populations of this area of our interconnected globe. In addition, local and international political leaders will have to find solutions to a demand that has to be met: the basic human right to health.

Our social responsibility demands that we share the great benefits that scientific knowledge produces and that we actively participate to ensure that the use of this knowledge is both ethical and equitable.

Genetics and health

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The roots of the current revolution in biology are found in fundamental research in biochemistry and microbial genetics. Those carrying out this work in the mid-20th century could not foresee the extraordinary current developments. They were motivated by human curiosity. Among the profound outcomes of their research was the demonstration of the universality of genetic mechanisms and molecules among all organisms. Consequently, current work with model organisms such as yeast, worms, flies and mice is essential to understanding human biology and applying that understanding to the improvement of human health. Plants, too, share the common genetic mechanisms, and research on plants is central to advancing the human condition. The various genome projects, aimed at determining the entire DNA sequence of the genomes of humans, the model organisms and selected other species, will contribute greatly and in unanticipated ways to the health of people worldwide.

Now, as we look to a new century and millennium, biology is poised to effect profound changes in human lives. Genetics has become the reference point for thinking about all biology and a compass for future research. It is also a partner to other sciences such as chemistry and ecology.

As we consider how genetics can contribute to human health, we need a broad view of the word ‘health’. Certainly it refers to the absence of disease and injury in individuals. But to be healthy, people should also be well nourished, enjoy a good physical condition, have access to clean water and live in a clean and comfortable environment. The definition of these conditions will differ from one community to another and with the age of the individual. To a remarkable extent, modern genetics can help achieve all these goals.

The techniques and knowledge of molecular genetics make possible reliable diagnoses of inherited and acquired genetic diseases such as cancer. Human alleles associated with disease and in some cases even with the likely severity of a disease can be detected. At present, these techniques are clinically feasible when the disease involves a mutation in a single gene. New methods promise to make such diagnostic procedures routine: in particular, there are automated techniques that use a variety of DNA ‘chips’ to screen thousands of sequences simultaneously and are linked through computers to genomic databases and the tools needed to use the databases. Chips are presently costly and not available worldwide. However, we can anticipate that that will change. With more research, they will be applicable to diseases and susceptibilities associated with multiple genomic loci. Presently, the rigorous study of inherited diseases is concentrated in countries with well-developed research enterprises in genetics. We need such research to be developed in other parts of the world so that a wider range of inherited diseases is defined and diagnosed.

Genetics has also provided new paths for the design and development of therapeutic agents. One such path, called gene therapy, would remove or inactivate or replace faulty genes. This has proved difficult and has not yet succeeded. What has succeeded is the use of cloned genes to synthesize therapeutically active proteins such as insulin, growth hormone and erythropoeitin. Another approach that appears to be fruitful is to use knowledge about the structure of the proteins encoded by specific genes to design drugs. Research of this kind on probably hundreds of genes occurs in laboratories of universities and small and large for-profit companies. Organizations that make such investments expect to recover costs and return a profit. Thus the price of the drugs will be high. The international community needs to explore ways to assure drug availability in poor communities and countries without discouraging development work.

One of the most interesting prospects for genetic medicine is the possibility of individualizing treatments. Cancers, for example, differ from one another in the genes associated with tumour formation. We may be able to tailor drug regimes to the array of mutations in a particular cancer. Also, for diseases other than cancer, a screen of a set of gene alleles in patients may predict which of several drugs is likely to work best and cause fewest side-effects in that individual. These are only a few examples of what the future may hold.

When we shift from considering the health of individuals to that of whole populations, research must focus on micro-organisms. Infectious diseases have their roots in the genes of pathogenic bacteria, protists, fungi and viruses. These genes are a leading cause of morbidity and mortality in the world. Also, the defence mechanisms of infected organisms depend on their own genes, be they humans or agriculturally important animals or plants.

By the 1950s, medical scientists believed that they could control many human and animal infectious diseases with a combination of improved sanitation, vaccines and antibiotics. That proved an optimistic illusion. Thus, many excellent antibiotics become useless as organisms evolve to resist their action. Other micro-organisms can alter their surface markers to compromise the effectiveness of immune responses and vaccines. Also, new or previously unrecognized pathogens emerge; HIV is the most devastating of these. The HIV epidemic has shown us that we do not fully understand the human immune system and also that the spread of infectious diseases is a global problem. Research is urgently needed for the worldwide control and treatment of infectious diseases.

Organized, shared, worldwide public surveillance is the key to the early detection of infectious disease epidemics. This is one reason why scientists are needed in all countries. Genetics gives us the ability to improve and enhance traditional surveillance techniques through screening for DNA sequences unique to particular organisms or their variants. DNA sequence identification is more reliable and can be faster than traditional methods. Internet networks for such data already exist.

Another advantage of DNA screening over traditional methods is the ability to recognize unsuspected, unknown and newly emerging pathogens. The genomes of more than 40 bacteria have been or are being sequenced. By comparing the gene sequences of pathogenic and non-pathogenic variants of micro-organisms including those that cannot be cultured, potential pathogenicity and virulence genes can be identified.

The convenience and precision of DNA screening is also useful for making sure that potential sources of infection are promptly identified. Many possible infectious contaminants can be identified by DNA screening using a single chip that includes sequences from all the usual suspects. Safe blood and blood products, food and water can be assured by routine screening for infectious agents.

Good nutrition and thus the provision of adequate and safe food supplies worldwide is an underlying prerequisite for good health. Conventional plant and animal breeding has, over many millennia, brought our species improved yields of essential foods. The introduction of cell culture methods into plant breeding has yielded greater efficiency and increased opportunities for desirable qualities. But some experts believe that these methods have achieved just about as much as they can. The new genetic engineering techniques offer great potential.

The genetic manipulation of agricultural species is, at present, a matter of international debate fed by different evaluations of the scientific data and different cultural and economic conditions. It is likely that different countries will come to different conclusions about where to strike an acceptable balance between the relative advantages and disadvantages of current agricultural practices, including their environmental effects, the potential environmental effects of the new, genetically engineered varieties and the need for producing more food. Every nation requires its own expert scientists if it is to make intelligent and productive choices. There are ways to formulate constructive governmental regulatory frameworks with which to deal publicly, effectively and scientifically with the important issues raised in each country. Scientists need to be sceptical and outspoken about national and international policies that are based on misconceptions and bad science and should take the initiative in applying modern genetics to the challenge of providing adequate food supplies in all regions.

Our species cannot continue to thrive if we destroy the Earth’s environment on which we depend in complex and poorly understood ways. There are enormous needs for new knowledge about known and unknown species and the nature of the interactions between species if biodiversity is to be preserved. New research is also required if we are to learn how to ameliorate the environmental degradation humans have already caused. And because biodiversity and environmental problems vary from one place to another, enhanced research efforts all over the world are essential. DNA sequences can be used in constructing a census of existing organisms. Transgenic plants have, for example, the potential to limit dependence on chemical pesticides and herbicides, increase agricultural productivity, produce commodities now made from fossil fuels and clear toxic wastes from soil.

There are many challenges ahead of us if all the world’s people are to experience improved health as a result of a century of genetic research. Fundamental to meeting those challenges is a need for all countries to investigate those potentials that can best promote the general welfare of their own people. Such participation requires in all countries a vigorous, respected and supported scientific research effort coupled to the education of new generations of scientists.

Application and implication of the cloning of a disease gene: cystic fibrosis as an example

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The most important revolution in biomedical science in the last two decades has been our ability to isolate various disease-causing genes and study the basic defects at the molecular level. This revolution is led by a number of major technological breakthroughs. DNA cloning and DNA sequencing are undoubtedly the two most important inventions in all biological sciences. The introduction of somatic cell genetics has created opportunities to study biochemistry and cell biology of mammalian cells, and also opened doors to the study of genetic diseases with cells from patients. High-resolution cytogenetic techniques and *in situ* hybridization analysis have allowed us to identify genetic aberrations and map genes at the chromosomal level. The highest impact made in disease gene research is probably the discovery of DNA sequence polymorphisms, initially as restriction fragment length polymorphisms and more recently as microsatellites, which have allowed us to map disease gene loci solely on the basis of family analysis.

Cystic fibrosis (CF) is a common genetic disorder in the Caucasian population. Patients with CF suffer from a variety of problems associated with the respiratory tract, gastro-intestinal tract, male reproductive tract and other exocrine malfunctions, including loss of electrolytes in their sweat. Progressive airway disease is the primary cause of morbidity and mortality in CF. The genetic nature of CF was first noted in the 1930s but its basic defect remained elusive for many years because of the multiplicity of complex symptoms associated with the disease.

The clear autosomal recessive inheritance of CF had given confidence to a number of groups of researchers that the disease gene could be isolated through family linkage studies. In 1995 Hans Eiberg and colleagues showed that it was possible to localize the CF gene next to another gene known as PON (paraoxonase). Later that year, our laboratory (in collaboration with a biotechnology company called Collaborative Research, Inc.) identified a polymorphic DNA marker linked to the CF gene. Since it was much easier to map the chromosome location of a DNA marker than that of PON (whose location was unknown), the CF gene was localized to the long arm of chromosome 7 by three independent groups, including ours, in the same year. Identification of a set of DNA markers closely linked to the disease locus immediately provided a physical target for cloning of the affected gene. In addition, the polymorphic markers could be used in genetic testing for the disease or carrier status in families with known patients. For CF, the fortuitous allelic association detected with some of the closely linked markers even permitted risk assessment for individuals without a family history of the disease.

The isolation of the CF gene was accomplished in 1989. Its encoded protein is named cystic fibrosis transmembrane conductance regulator or CFTR. Significant progress has since been made regarding our understanding of CF in the past 10 years. The primary defect in CF has been attributed to the loss of a cAMP-activated Cl ion conductance and an up-regulation of sodium ion reabsorption from the secretory epithelium. From the deduced amino acid sequence, CFTR is predicted to contain 12 membrane-spanning domains, two nucleotide-binding domains and an R-domain thought to have a regulatory function in ion conductance. A large volume of data, based on cDNA expression studies in cell cultures and reconstitution in planar lipid bilayers, has provided strong evidence that CFTR functions as a cAMP-inducible chloride channel located at the apical membranes of epithelial cells. Recent data suggest, however, that CFTR can also regulate the epithelial cell-specific sodium channel and the outwardly rectifying chloride channel.

The most common CF mutation is a 3-bp deletion (δF508) which accounts for about 70% of CF chromosomes worldwide. The prevalence of δF508 varies significantly among different geographic regions. In addition, there are over 800 other mutations that have been identified, although most of them are rare and some appear to be population specific. The mutation data have been widely applied in DNA diagnosis and carrier testing. CF mutation screening has also been incorporated in the newborn screening programmes in some countries and states. For most northern European populations, the overall mutation detection rate is about 85%. For certain relatively homogeneous populations, the coverage may approach 95-100%. An international CF Genetic Analysis Consortium and several working groups have been established to collect CFTR mutation data and to perform genotype-phenotype correlation studies[1].

In terms of the molecular consequence of each mutation, some general conclusions could also be drawn and five mutation classes may be summarized as follows. Class I represents mutations that give rise to truncated product or no protein at all and, consequently, absence of CFTR Cl-channel function in epithelia normally conferred by this protein. Most stop codon, frameshift and splice mutations would be so classified. In Class II, full-size mutant proteins are made but they fail to translocate to the apical membrane for proper function. It is of interest to note that δF508 is a typical Class II mutant; δF508 protein is capable of escaping the ER if the cell culture is placed at room temperature (instead of 37°C) or in the presence of osmolytes; its channel properties appear to be normal once the mutant protein reaches the cell membrane. In contrast, the Class III mutant proteins are capable of reaching the plasma membrane, but they cannot open its channel upon cAMP and ATP stimulation. For all the Class IV mutations, the mutant proteins can reach the apical membrane and generate cAMP regulated channel activity, but its activity is generally reduced. In Class V, the mutant allele causes a reduction in the synthesis of normal CFTR, either at the mRNA or protein level. The detailed properties of the mutant proteins should prove to be useful in disease management and treatment.

The clinical presentation of CF is heterogeneous, however. Besides marked variability in age of diagnosis, the severity of disease and its rate of progression also vary considerably for different organs. Nevertheless, some of the variability could be explained by the spectrum of mutations. For example, there is a good genotype-phenotype correlation for pancreatic enzyme function. Accordingly, patients with two ‘severe’ mutant alleles are found to be mostly pancreatic enzyme insufficient (PI) and patients with one or two ‘mild’ alleles are almost exclusively pancreatic sufficient (PS). It is also of interest to note that PS patients are generally diagnosed at a later age and found to have lower sweat chloride levels, better pulmonary function and better survival as a group.

CFTR mutations have also been detected in a number of seemingly unrelated diseases, such as male infertility, including congenital bilateral absence of vas deferens and obstructive azoospermia, and various pulmonary diseases, including chronic obstructive pulmonary disease and asthma. Besides the fact that typical CF mutations are found in a proportion of patients much higher than that anticipated for a random population, there is also a high prevalence of certain CFTR variant alleles which are otherwise known as ‘benign’ amino-acid substitutions.

Unfortunately, it is difficult to offer prognosis to individual patients based on CFTR genotype alone. It is clear that the clinical heterogeneity of CF is not only determined by the genotype at the CFTR locus. Patients with the same CFTR mutations, and even patients in the same family, do not necessarily have the same disease presentation. This variation is thought to be due to differences in additional genetic factors and environmental influences. Using a CF mouse model, we recently mapped a major modifier gene locus for intestinal obstruction during their early life. The same modifier gene appears to exist among CF patients. More recently, by introducing the CFTR mutation into different genetic strains of mice, we have found that CF mice could develop lung and liver diseases. Therefore, these observations suggest that it would be possible to map the respective modifier genes for the CF lung and liver diseases. Understanding the modifying factors should allow us to devise alternative strategies to treat CF patients.

In conclusion, although we have learned a great deal about cystic fibrosis since the cloning of the causative gene and the identification of a large number of mutations, we are still far from having a complete understanding of the basic defects in this disease. All the current treatments are still targeted at the symptoms. It is encouraging, however, that some of the clinical trials based on the little we know about the basic defect appear to be moving in the right direction. DNA diagnosis has become routine procedure in the laboratory. CFTR mutation analysis has also helped in understanding the aetiology of some of the related diseases and led to practical use in genetic counselling. Clinical trials have been initiated for CF gene therapy, osmolyte therapy for δF508 carrying patients and aminoglycoside for patients with nonsense mutations. Lastly, our work on the modifier genes should provide more accurate parameters for disease prognosis and the means to develop novel strategies for CF treatment. It is anticipated that the Human Genome Project will give even more insight into many common diseases, such as asthma, diabetes, rheumatoid arthritis and various neurological and mental illnesses, which afflict a much larger human population.

Note

1. The cystic fibrosis mutation database can be accessed through the Internet via the website http://www.genet.sickkids.on.ca/cftr/

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New perspectives on ageing

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At the end of the 20th century the most important demographic change is the increasing number of the aged. Comparing the changing numbers of individuals aged 60 years and over in more developed and less developed countries it is apparent that after 2000 there will be a significant increase in the less developed countries too. In many countries of the world the oldest among the aged (80 years and over) are the fastest-growing proportion of the elderly. The number falling into this age group will increase in the 21st century in developed regions as well as in developing regions.

Advances in sciences and medicine in the 20th century have resulted in millions of people achieving extended longevity through advances in public health, in living conditions, through modern therapy, through a change in life style. Longevity has become the striking feature of our century. In addition, the pattern of diseases has changed dramatically. In recent years, the principal cause of death in the population has shifted from infectious diseases towards chronic diseases. Unfortunately, improved life expectancy has not ensured freedom from diseases (Beregi, 1985).

Chronic diseases will be the major public health problem in the 21st century. About 10% of the population in the European region suffers from long-term disability. This will increase as the population grows older. Recent research suggests that, in the future, those under 75 years of age will be healthier, but those over 85 years will be frail and disabled. This demands new priorities, new thinking and new action.

The main causes of disability are cardiovascular diseases, locomotion disorders, sight and hearing problems, injuries and mental disorders. People with disabilities can be helped to lead satisfying and productive lives through improvement of the physical and social environment using new technology.

There are marked differences in health status between the more and the less privileged groups within countries. There are apparently close links between social status, occupational career and better housing conditions resulting in a lower susceptibility to illness and better health care (Ross, 1989). The finding that the level of education is related to good functioning could be explained by healthful habits, better nutrition and using more preventive health services.

In the future the highest priority should be given to prevention of the most common disabling conditions, such as cardiovascular diseases, cancer, accidents and violence. Extensive research is needed to find effective ways of preventing rheumatic conditions and mental diseases in old age.

Health-preserving possibilities are:

- to improve diagnostic methods, rehabilitation techniques and therapy;
- to use organ replacement and transplantation in the elderly, too;
- to examine the causes and changes of age-related alterations and non-fatal chronic diseases;
- to find the connection between physiological age changes and age-related diseases;
- to develop new therapies in mental diseases and chronic illnesses.

The main priorities to improve the heath of the elderly could be summarized as follows:

- preventive measures:
  - to screen for cancer, for diabetes, for hypertension;
  - vaccination programmes;
  - mental hygiene programmes to prevent suicides;
  - health education, to change lifestyles;
- to increase the number of rehabilitation services;
- services should be adapted to the needs of the elderly;
- greater number and greater variability in health care systems;
- to expand home care services with rehabilitation.

During the 20th century, the average educational level and socio-economic conditions of the elderly have improved. These changes have resulted in better functional capacity, in better health and more activity. We are living longer and working for a lesser number of years, therefore a large economic gap is being created. The active group of the aged is growing; they are physically fit and psychologically ready for stimuli and challenges. They have many years of active retirement in front of them, but today they receive very little recognition.

The general population is prejudiced about elderly people, they have insufficient information and they connect old age with diseases and senile changes. The unfavourable attitudes of society fail to encourage the elderly population to maintain and develop their functional capacity and health. This attitude is also influencing the treatment of elderly people, though aged people should receive the same medical treatment as young ones (Heikkinen, 1987). We have to mobilize this group, so that its members can fully realize their potential contribution to society. A higher educational level will lead these patients to demand more possibilities in the life of society and more choice in the health care system. The latter will stimulate a better quality of care (Birren, 1985). A major concern now would be to provide opportunities for the growing numbers of retired persons to find social, cultural and recreational activities to use their time profitably, to remain integrated with society and enjoy a full life. We hope the future society will become more responsible, cooperative and caring.

The 20th century was the century when scientific discoveries resulted in several basic and practical issues; this century was beneficial for mankind, for the aged. The coming century will be the century of the practical use of high technology in monitoring health status, controlling diseases, eliminating environmental hazards and promoting health education and disease prevention.

We are on the threshold of benefiting from technological advances that were little more than fantasy in the past. Progress in pharmacology, biology and immunology, knowledge gained from the new imaging techniques, positron emission tomography and nuclear magnetic resonance should give us a more rational basis for treatment (Carlsson, 1985).

New discoveries in cellular, molecular and submolecular levels, diagnostic development and new therapeutic possibilities are resulting in reducing morbidity and extending the healthy lifespan now and in the coming century. Science is indefinitely perfecting human knowledge and will lead to a prolonged healthy lifespan. The scientific resources that we can bring to bear to propagate prevention are greater now than ever in history, through telecommunications technology and the Internet.

If we can combine the new technologies with social and psychological support, which are equally important, we can look forward to a time when these advances together will provide more opportunities for a meaningful existence late in life.

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Vaccines for the future

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Vaccines and vaccination are at a turning point. Although vaccination has been demonstrated to be the most effective way of preventing infectious diseases, its major public health impact has been restricted to the control of a limited number of human diseases including smallpox, poliomyelitis, neonatal tetanus, diphtheria, pertussis and measles. Vaccines currently in clinical use have been developed through relatively simple, largely empirical approaches. However, recent advances in microbial genetics and in immunology have opened the way towards a revolution in ‘vaccinology’ and new vaccine strategies based on the understanding of microbial pathogenesis and of host defence mechanisms are emerging.

Within the next 10 to 15 years, a whole set of new preventive vaccines against infectious diseases or neoplasm and some therapeutic vaccines should become available. Their potential impact on global mortality due to infectious diseases could reach 9 million prevented deaths per year, if new vaccines against pneumonia, meningitis, diarrhoeal diseases, malaria, tuberculosis and possibly AIDS become available.

After the progressive introduction of hepatitis B immunization and its preventive effects on liver cancer, the benefit of vaccination should also be extended in the near future to the prevention of cancers associated with *Helicobacter pylori* (55% of stomach cancers) and with papilloma viruses (over 80% of endocervical cancers). Some other cancer vaccines based on the use of tumour antigens (e.g. melanoma) have now entered the phase of clinical trials. Therapeutic vaccines that aim at restoring a ‘normal’ immune response to major allergens are already produced against increasingly prevalent allergic diseases, whereas preventive and therapeutic peptide vaccines for autoimmune diseases are on the drawing board.

Progress in microbial genetics and advances in genetic engineering are an essential part of the ongoing vaccine revolution. Identifying the molecular basis of virulence and microbial antigens essential for the induction of successful host defence mechanisms allows the construction of ‘intelligent’ vaccines, such as genetically engineered attenuated micro-organisms or live vectors carrying foreign genes relevant for protection. Attenuated strains can also be used as vectors carrying foreign genes into their bacterial genome. Deciphering of the entire genomes of most important human pathogens will also have a marked impact on vaccine development.

Understanding protective mechanisms, i.e. molecular processes involved in the immunological recognition of microbial antigens and in the differentiation of cells which mediate effector mechanisms, are generally required for the design of new vaccines against diseases for which an empirical vaccination approach has failed. In order to be protective, vaccines should be designed to elicit appropriate protective immunological effects. Whereas antibody responses are sufficient to protect from infections by pneumococci or meningococci, additional cellular responses are usually needed to prevent diseases caused by intracellular micro-organisms such as viruses, chlamydiae, certain bacteria (mycobacteria) or parasites (malaria, leishmania), capable of hiding and surviving within the environment of the infected cells. It is now becoming feasible to design vaccine formulations which can polarize vaccine-induced responses towards a desired pattern.

However, the increasing availability of new vaccines raises issues which limit their introduction into routine use. A number of parents are already concerned about the high number of vaccines administered to their young infants and even vaccines that have already been demonstrated for years to be efficient are not being optimally used to protect those who need it most. As vaccine-related adverse events may become more visible than some vaccine-preventable diseases, efforts to maintain a high level of vaccination coverage for the benefit of the community are often jeopardized by organized efforts of opponents to immunization. Finally, major obstacles to the global use of new vaccines are of an economic nature.

How to overcome the AIDS crisis: the view of a scientist

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The AIDS epidemic is the prototype of a newly emerging disease which might bring about devastating effects on our civilization, if we do not find the solutions to control it. It is also an example of a complex interplay between biological factors, socio-economic, behavioural and cultural factors. As a result, biomedical solutions will be necessary but not sufficient to solve the entire problem.

The dimensions and the dynamics of the epidemic are quite impressive. Beginning from a few cases diagnosed in 1981 in the USA (and retrospectively in Africa in the 1970s), there is now a pandemic invading all the continents, with more than 35 million people living now with HIV, most of them at the AIDS stage. Among them are many women and children. If we consider the dynamics of the infection, we see a continuous and rapid rise in southern Africa, India and China, while there is more or less stabilization in northern industrialized countries, with the exception of the member countries of the Russian Federation, in which the number of new HIV infections is now growing exponentially. This catastrophic situation has occurred despite very rapid advances in knowledge of the causative agent and the design of relatively efficient treatments.

The triple therapy which has been widely used in industrialized countries since 1996, and only sparsely in developing countries, has significantly decreased the frequency of opportunistic infections and the death toll in 2-3 million HIV-infected patients. This achievement, however, has some important limitations. The treatment is very expensive (US$ 12 000 per year) and has to be given daily and continuously. Severe side-effects (diabetes, hyperlipidemia) may appear, as well as mutants of the virus resistant to the antiretroviral drugs. And there are virus reservoirs (latently infected cells) which impede any eradication of the infection. Finally, the monitoring of the treatment requires some specialized laboratory structures (molecular measurements of viral load, CD4+ cell counts).

Table 1. **Some milestones in the treatment of AIDS**

1981	Identification of the disease in the USA
1983	First isolation of HIV
1984	Confirmation of HIV as the causative agent of AIDS – biological and molecular characterization
1985	First blood tests to eliminate transmission of HIV by blood transfusion
1986	Isolation of HIV-2
1987	First use of AZT as an antiretroviral drug
1991	Apoptosis as a mechanism of cell death in AIDS
1995	Decrease of HIV perinatal transmission with AZT
1995	Demonstration of high rate of HIV replication during the silent period of infection
1996	Identification of HIV main co-receptors
1996-97	Generalization of highly active antiretroviral therapy (HAART) in developed countries

This is why only 10% of the infected patients in the world can have access to this treatment and why research should double its effort to find better solutions. Four main lines of research remain to be explored:

1. The role of co-factors in the transmission of the virus, especially in tropical areas

It is striking that heterosexual transmission of HIV is the main route of spreading the epidemics in southern countries, whereas it is very limited in northern, industrialized areas. Unlike syphilis and other sexually transmitted agents, vaginal transmission of a retrovirus like HIV is unusual and requires some intercurrent infections leading to inflammation.

Another possible route in women is the endocervix, which has a more fragile mucosa (monoepithelial). It has already been shown that antibiotic treatment effective on bacterial STDs has reduced the transmission of HIV in African women. However, much still remains to be done to explain the high rate of transmission in women and identify the biological co-factors involved, aside from socio-cultural factors. This investigation may be highly cost-benefit effective by leading to new ways of treatment (local bactericides and virucides) and vaccines.

2. The role of HIV in AIDS pathogenesis

The mechanism by which HIV infection progressively destroys the immune system is unclear. The simplistic view that it can be solely explained by the direct destruction by HIV of the infected lymphocytes is no longer sustainable. In fact, many uninfected lymphocytes in the blood and lymph nodes of HIV-infected individuals are in a preapoptotic state and spontaneously die in *ex vivo* culture. These are mostly CD4+ cells.

It is likely, although not proven in the *in vivo* situation, that this is caused by the action of some HIV proteins released by infected cells, such as the surface glycoprotein gp120 or its precursor, gp160, and two regulatory proteins such as Tat and Nef. The latter proteins should therefore be potential new targets for therapeutics and also for vaccines.

3. Treatments accessible to all HIV-infected patients

An important advance in triple therapy would be a reduction in its dosage and duration. Many more patients of developing countries could for instance afford a one-year treatment, which could reduce the virus multiplication to a lower level for a longer period of time.

This goal is achievable if we can increase the restoration of the immune system by complementary treatments, such as antioxidants and immunostimulants. Products coming from traditional medicine could be tested in rigorous trials, since the laboratory tests to evaluate their effectiveness are now available.

4. Preventive vaccine

But it is clear that the epidemics will not be decreased and finally stopped without the massive use of a preventive vaccine, while continuing the appropriate measures of education and prevention.

Such a vaccine should meet the following requirements:

- Absolute safety with no potential for long-term harmful effects, since the vaccine will be given to children or young adults. This would eliminate any candidate vaccine based on live attenuated HIV.
- Be active on the HIV strains circulating in the world. HIV has a high potential of variability and the most immunogenic parts of the surface protein (gp120) are highly variable, defining subtypes with different geographic distribution. As the epidemic expands, more people are infected by two subtypes, so that new recombinant variants appear.
- Prevent the mucosal transmission of the virus by inducing local immunity.
- Induce broadly neutralizing antibodies, cell-mediated immunity and soluble inhibitory factors; this immunity should last sufficiently to avoid repeated injections.
- If the vaccine does not induce complete sterilizing immunity, it should at least lower the viral load sufficiently to prevent disease for a long time.

Such a vaccine does not exist right now for the following reasons:

- The lack of an appropriate animal model. The only closely related animal model is the rhesus macaque, which can be infected by SIV, a virus close to HIV-2 but distinct from HIV-1.
- The conservative approach of vaccinologists. Since most antiviral vaccines are based on the induction of antibodies to the viral surface glycoproteins, the same approach has been followed for HIV. After 10 years of preclinical studies and several phase 2 trials, it is becoming clear that the approach using the intact glycoprotein of HIV is not going to work. It is actually part of the virus strategy to escape the immune response by exposing the most variable sites of its surface proteins. On the contrary, in a vaccine, such highly variable immunogenic sites should be removed or conformational changes should be induced, so that more conserved sites are exposed and used for immunization.
- In addition, the induction of mucosal immunity, which is absolutely necessary to block sexual transmission, has not been sufficiently considered.

- The relative lack of interest on the part of the pharmaceutical industry and funding agencies. This is because the market for such a vaccine will reside mostly in countries unable to afford its price. There is also a still widespread belief among decision-makers that prevention measures and treatment will be sufficient to control the epidemics and that a vaccine is not feasible.

On the contrary, it is the strong feeling of the author that an HIV vaccine is feasible. There are already examples of natural resistance to HIV. In Kenya, some sex worker women, exposed many times to HIV, still do not get infected, at least by the seroconversion criterion. It has been shown that such women harbour in their vaginal mucosa specific antibodies (IgA) capable of neutralizing the virus, as well as some cellular immunity. Moreover preliminary results in monkeys indicate that immunization against Tat and Nef proteins can protect from the disease induced by HIV. Finally there are new ways of antigen presentation (virosomes) which could induce both systemic and mucosal immunity, with a complete insurance of safety.

Together with several European and American laboratories, our researchers, within the network created by our Foundation, are working on the following vaccine project called the Composite AIDS vaccine or COMBHIVAX. The concept is to induce in the vaccinees two lines of defence:

- Induction of local mucosal immunity. Several conserved peptides of the gp120 and gp41 are associated with virosomes (virosomes are liposomes stabilized by the influenza virus glycoproteins).
- Induction of immunity (both cellular and humoral) against recombinant Tat and Nef proteins either by virosomes or by a live viral vector.

We are conscious that this is not the only possible formulation for a vaccine, but the only way to prove or disprove its efficacy is to go ahead and test it in clinical trials as soon as possible.

La révolution biologique : quels enjeux pour l’Afrique ?

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A l’orée de l’an 2000, malgré les différentes stratégies mises en œuvre ces dernières années, et ce, dans le cadre d’une politique régionale adoptée à l’échelle du continent – OMS/AFRO –, la situation sanitaire de l’Afrique demeure préoccupante. On observe une recrudescence des maladies transmissibles, une émergence de maladies « nouvelles », un poids particulier des maladies héréditaires, tout ceci en liaison avec l’ignorance et la pauvreté des populations concernées.

La progression fulgurante de l’épidémie due au VIH en Afrique sub-saharienne et les énormes difficultés rencontrées pour maîtriser son expansion et en réduire l’impact socio-économique et culturel illustrent assez bien, d’une part, le dysfonctionnement du système de santé, d’autre part, la faible implication des communautés dans la prise en charge de leurs propres problèmes de santé.

Dans un tout autre domaine, celui des maladies génétiques, des hémoglobinopathies majeures sévissent à grande échelle sur le continent. Ainsi, dans la zone intertropicale, on décrit la ceinture sicklémique de Lehmann, où le trait drépanocytaire atteint des fréquences maximales avec des taux de fréquence variable, à partir de 7 %, progressant de l’ouest vers l’est et du nord vers le sud et pouvant atteindre jusqu’à 40 % de la population dans certaines régions du Congo et de l’ex-Zaïre. Dans cette zone, d’autres hémoglobinopathies ont été reconnues (hémoglobine C, alpha et bêta thalassémie). Pour les thalassémies l’ampleur du problème n’a pu être pleinement évaluée que depuis les progrès obtenus en génétique moléculaire. Néanmoins, on ne peut pas dire que depuis les années 1977-1978, date du premier clonage de gènes humains – les gènes de l’hémoglobine – les populations affectées par ces anomalies de l’hémoglobine et vivant en Afrique sub-saharienne, ont vraiment bénéficié des résultats de cette recherche ! Loin s’en faut ! Elles participent pourtant à l’épanouissement de cette recherche, la drépanocytose est un des modèles les plus utilisés en génétique moléculaire ; combien d’érythrocytes collectés sur ces populations n’ont pas fait le voyage du sud vers les laboratoires très spécialisés du nord ?

Et pourtant les scientifiques chercheurs dans le domaine médical originaires d’Afrique comme du monde entier ont été, dès le début de la révolution biotechnologique des années 1970, particulièrement enthousiasmés par ces nouvelles technologies qui, en rendant les gènes humains directement accessibles à l’analyse, permettaient de déchiffrer la programmation des êtres vivants, de dépister les anomalies, rendant plus compréhensibles les maladies. Tout devenait alors possible: le diagnostic des maladies, leur traitement, voire leur prévention.

Trente ans plus tard, qu'en est-il pour l'Afrique ?

Qu'il me soit permis de rapporter des faits historiques récents qui sous-tendent mon désarroi de chercheur africain et justifient mon engagement pour le développement de la science en Afrique au service des communautés, au service de la collectivité ! Peu d'entre nous, très peu de chercheurs d'Afrique ou d'ailleurs connaissent réellement la participation des scientifiques d'Afrique de l'ouest à la découverte du vaccin de l'hépatite B et à sa mise sur le marché.

Pourtant ces faits devraient être inscrits définitivement dans la mémoire de l'histoire de la médecine au niveau mondial et régulièrement rappelés au souvenir des scientifiques et des décideurs politiques, notamment ceux vivant et travaillant pour ou sur le vieux continent !

Saviez-vous que l'hypothèse de la filiation Hépatite B-Cirrhose-Cancer primitif du foie a été pour la première fois testée à l'Ecole de médecine de Dakar, dans les années 1950 ? Saviez-vous que les générations d'enfants, de femmes, d'hommes du district de Santé de Niakhar – petit village situé à quelques centaines de kilomètres de Dakar, capitale du Sénégal – et leurs voisins de la république de Gambie ont donné régulièrement sérums et pièces d'autopsie, prélèvements de base pour cette recherche. Des générations de mères et leurs nouveaux-nés ont été soumis pendant des années à des séries de prélèvements sanguins puis à des protocoles expérimentaux de vaccination. Saviez-vous enfin que la découverte de DNA viral intégré dans des cellules d'hémopathomes est le fruit d'une collaboration harmonieuse entre des équipes de chercheurs du Nord (Faculté de médecine de Tours et Institut Pasteur de Paris en France) et d'équipes du Sud (Faculté de médecine de Dakar au Sénégal) et d'une implication bénévole de communautés villageoises ?

Comment ne pas être choqués, nous chercheurs originaires de ces régions, par le fait que la vaccination contre l'hépatite B, qui protège non seulement d'une maladie infectieuse hautement transmissible, mais aussi d'un cancer « endémique » dans ces régions, ne soit pas encore accessible de nos jours, au moins à la population à risque que sont les femmes et les enfants en bas âge. Ne serait-il pas temps que ce vaccin soit intégré au programme élargi de vaccination mis en œuvre dans ces pays ? A la fin de ce XXe siècle, la communauté scientifique est en droit de se demander si réellement la politique sanitaire mise en œuvre depuis près d'un quart de siècle (conférence internationale sur les soins de santé primaires tenue à Alma-Ata en 1978), l'état actuel des systèmes de santé et de recherche et des structures, ont été suffisamment adéquats pour répondre efficacement aux grands défis que l'Afrique se devait de relever dans l'objectif de la « santé » pour tous d'ici l'an 2000.

Bien que, depuis lors, des efforts ont été déployés aux niveaux mondial, régional et national pour soutenir les actions entreprises au niveau national pour atteindre cet objectif, le bureau régional de l'Organisation mondiale pour la santé (OMS) pour l'Afrique annonçait à la réunion du comité consultatif africain pour le développement sanitaire (CCADS) en avril 1996 : « A mesure qu'approche l'échéance de l'an 2000, il est de plus en plus évident que le délai fixé pour atteindre l'objectif de la santé pour tous ne sera pas atteint universellement, notamment pour les pays africains, en dépit des progrès réalisés dans les 17 dernières années en ce qui concerne l'allongement de la vie, le déclin de la mortalité infantile, l'amélioration de l'accès aux services de santé de base. En Afrique sub-saharienne, les ressources consacrées à la santé restent insuffisantes. Aucun état n'y consacre les 9 % de son budget comme recommandé par l'OMS. Néanmoins, malgré la crise économique sans précédent que connaît l'Afrique, certains pays arrivent à réaliser de bonnes performances de relance économique. Pourtant, il doit y avoir un moyen d'obtenir des résultats appréciables en matière de développement sanitaire. »

Ainsi, bien que ces objectifs n'aient pas été entièrement atteints, la santé pour tous d'ici l'an 2000 a constitué pour tous les pays un objectif motivant et opérationnel à la fois, et a également servi de concept unificateur dans les travaux ayant un caractère international en matière de santé, ce qui a contribué de façon importante à l'instauration d'une meilleure santé dans le monde et en particulier en Afrique. Ceci a contribué aussi à des échanges d'expériences intéressants entre scientifiques, chercheurs, décideurs et politiques originaires de différentes régions du monde.

Pouvons-nous alors, nous scientifiques – chercheurs vivant en Afrique, impliqués sur le terrain au quotidien – pouvons-nous nous laisser aller à cet afro « pessimisme » de fin de siècle et répéter avec tous les autres que rien ne va, rien n'ira ?

Depuis longtemps déjà, les autorités politiques et sanitaires des pays africains ont opté pour le développement d'une médecine préventive à assise communautaire, plutôt que celui d'une médecine curative forcément réservée à une élite.

Ce choix certes judicieux face aux enjeux réels en termes de santé publique n'a-t-il pas occulté le rôle de la recherche en santé pour un développement sanitaire harmonieux intégré dans une biologie qui veut qu'aucun développement durable, aucun développement réel ne soit envisageable sans réflexion, sans programmation préalable. En fait, aucune solution ne peut être apportée à un quelconque problème sans en avoir fait un énoncé correct et précis.

La révolution biologique provoquée notamment par l'application des concepts et des techniques de biologie moléculaire en médecine ne permet-elle pas d'envisager pour l'Afrique une médecine qui, en recherchant l'origine des maladies au niveau du gène, permet de prédire pour mieux prévenir et en même temps de guérir et de faire régresser l'incidence de telle ou telle pathologie en traitant le mal le plus tôt possible ? Cette révolution biologique qui couvre tous les domaines de la science médicale – diagnostic, traitement, prévention des maladies, ne réconcilie-t-elle pas en Afrique, d'une part, les décideurs politiques et économiques et les chercheurs scientifiques, d'autre part, les chercheurs et les communautés affectées ?

Le chercheur africain en biologie se pose encore beaucoup de questions :

1. A l'aube de l'an 2000 pour les populations du vieux continent, y aura-t-il des acquisitions nouvelles en génétique moléculaire ?
2. Suffisamment de cadres et d'équipes ont-ils été formés pour poursuivre des recherches fiables (haut niveau de qualité, diffusion) dont les résultats seraient utilisables en vue d'une régression sensible de l'incidence de certaines maladies du continent ?
3. La formation des cadres africains dans les pays du nord prend-elle réellement en compte l'objectif de transfert de technologie pour une pérennisation des acquis et la poursuite d'une activité fructueuse ?
4. Les budgets mis à disposition par les gouvernements pour la recherche sont-ils conséquents et en adéquation avec les besoins prioritaires des populations ?
5. Existe-t-il de réelles collaborations des équipes africaines avec celles des pays développés mieux nantis, pour une recherche en partenariat ?
6. Les financements obtenus pour certains travaux en partenariat sont-ils suffisamment promoteurs pour les équipes du sud ?

Après une analyse de la situation actuelle de la recherche en biologie moléculaire en Afrique sub-saharienne, nous envisagerons les stratégies possibles pour améliorer les performances des équipes de recherche pour une meilleure santé des populations.

Situation actuelle de la recherche en biologie moléculaire en Afrique sub-saharienne

Considérée par les décideurs politiques et économiques comme une science de luxe à réserver aux pays nantis, la biologie moléculaire trouve peu de « preneurs » en Afrique sub-saharienne. Ainsi, la formation dans ce domaine ne figure pas parmi les programmes prioritaires, et les financements pour la recherche en biologie moléculaire sont très difficiles à obtenir aux niveaux national et régional.

Pour ne pas dire qu'ils sont pratiquement inexistants des institutions de recherche. Pourtant, il existe dans plusieurs pays de la région des équipes de chercheurs qui pratiquent une recherche en biologie moléculaire de niveau international, dont le financement vient presque exclusivement de partenaires au développement, de divers bailleurs dont des investisseurs privés étrangers, des institutions de formation et de recherche, des industries pharmaceutiques multinationales ; ceci est heureux, mais induit une certaine précarité dans la durée de l'activité. Citons quelques exemples en Afrique Francophone : équipe du Professeur Souleymane Mboup de l'université Cheikh Anta Diop de Dakar au Sénégal, travaux sur les variants VIH1 et sur VIH2 (génotypes), différents virus ou cogènes ; équipe du Dr Vab de Per du Centre MURAZ-OCGE à Bobo Dioulasso (Burkina-Faso) ; équipe du professeur Mireille Dosso de l'université de Cocody à Abidjan (Côte d'Ivoire) travaux sur l'ulcère de Buruli, travaux sur les myobactéries ; équipe des professeurs Mireille David et Y. Segbena de l'université du Bénin au Togo, travaux sur la transmission mère-enfant du VIH, confection du virus de l'hépatite et VIH. Ces différentes équipes ont depuis quelques années fourni des résultats très intéressants dont la diffusion au niveau de la communauté s'est faite par voie de publication scientifique, mais dont l'impact sur le développement des pays et sur l'amélioration de la santé des communautés n'est pas vraiment perçu par les autorités politiques et économiques, encore moins par les communautés elles mêmes.

Financement et ressources humaines disponibles

Globalement, la place de la recherche en Afrique est faible. En effet, elle ne représente que 0,4 % des ressources humaines et financières, et 0,3 % de la production scientifique mondiale publiée.

Les crédits budgétaires alloués aux centres et institutions de recherche sont encore, pour tous les pays de la région, en deçà des 1 % du PIB, limite fixée par le plan d'action de la recherche CASTAFRICA I élaboré à Lagos (Nigéria) en 1974. Or, toute recherche en biologie, en particulier en biologie moléculaire, recherche fondamentale, n'est réalisable que par une mobilisation de ressources importantes tant en quantité qu'en qualité – ressources humaines et matérielles – en plus de se maintenir à un niveau dynamique compétitif qui en aggrave le coût, avec la nécessité d'un réajustement permanent des ressources mobilisées.

Pendant longtemps, au niveau de la communauté scientifique mondiale, la recherche fondamentale pure s'est développée sans vraiment tenir compte des réalités environnementales. Ainsi ont été faites la plupart des grandes découvertes plus ou moins fortuites, fruit du travail de chercheurs inspirés ayant laissé libre cours à leur génie imaginatif. Peut-on se permettre, à l'heure actuelle, de promouvoir en Afrique sub-saharienne ce type de recherche aux dépens de la recherche appliquée dont les effets sont immédiatement et clairement perçus par le profane et par les politiques qui, eux, ont obligation de répondre aux besoins du présent sans compromettre les ressources actuelles et futures.

Faudrait-il alors continuer d'envisager la solution des problèmes de santé propres à notre continent uniquement à travers l'expérience des autres, en ne partant que des résultats de la recherche fondamentale réalisée hors du continent et notamment dans les pays du nord ? Une telle option ne viendrait-elle pas cautionner un phénomène de fuite en avant, en négligeant une recherche fondamentale en Afrique francophone conçue par les Africains et pour les Africains, en oubliant de fait que ce type de recherche est un élément essentiel du développement.

Il faut aussi souligner le fait que, dans beaucoup de pays de l'Afrique francophone sub-saharienne, la masse critique nécessaire et suffisante pour mener des activités de recherche correcte n'est pas encore atteinte. On y constate aussi une disparité en termes de niveaux de formation. Cette analyse rapportée à la recherche fondamentale, aboutit à un tableau encore plus sombre qui justifie l'impatience des uns, la déception des autres et enfin la tendance des décideurs, responsables nationaux et internationaux, à envisager des stratégies nouvelles, voire des solutions radicales tenant compte essentiellement des contraintes financières, dont celle de promouvoir plutôt, et même exclusivement, la recherche appliquée. Quel devenir pour tous les chercheurs formés, les chercheurs en formation, les structures de recherche déjà fonctionnelles ?

Peut-on à présent sacrifier toute une génération de chercheurs en la réduisant à une inactivité de fait, favorisant parallèlement la fuite des cerveaux, fruits de tant de sacrifices, résultats de tant d'investissements ? Peut-on accepter une telle dépendance du continent ?

Peut-on cautionner la marginalisation de l'Afrique francophone sub-saharienne en ne prenant pas en considération les bénéfices pour le monde entier d'une recherche africaine spécifique bien menée ? Malgré toutes les difficultés, peut-on envisager des effets sur le développement d'une recherche sans fondement, d'une recherche sans régularité, sans continuité dans l'effort ? La recherche-développement passe par la recherche fondamentale. En effet la recherche fondamentale permet de répondre de manière spécifique au problème posé, et ce, de manière répétitive. Ainsi promouvoir ce type de recherche dans un contexte précis, au sein d'un espace environnemental donné, présente un intérêt certain et permet d'éviter le gaspillage des ressources, en l'intégrant dans des plans de recherche adéquats, établis en fonction des priorités des pays.

Pour redonner ses lettres de noblesse à la recherche fondamentale en Afrique francophone sub-saharienne, il apparaît urgent, d'une part, d'évaluer les ressources disponibles, d'autre part, d'envisager des stratégies nouvelles pour son financement et la gestion des résultats obtenus.

Evaluation des ressources disponibles

Cette évaluation concerne différents chapitres :

- Institutions d'éducation et en particulier de formation à la science : principes de base.
- Ressources humaines (mise à jour ou établissement d'un annuaire des chercheurs au niveau de la région et par spécificité).
- Structures et institutions de recherche.
- Mécanismes de coordination et de gestion aux niveaux national et régional :
  - réseaux de chercheurs ;
  - réseaux de financement de la recherche dans la région ;
  - réseaux de communication des informations.

Stratégies envisageables

Il s'agit de mettre en œuvre une recherche fondamentale originale, support de la recherche-développement et véhicule de formation. La promotion d'une recherche fondamentale pour le développement a pour exigence première la définition des priorités pour l'Afrique francophone sub-saharienne, à travers des plans à court, à moyen et à long terme. Ainsi pourraient être élaborés les axes de recherche et dégagés, au niveau de la région, des pôles d'excellence qui pourraient servir de référence.

L'exploitation des résultats et des compétences pourrait être envisagée au sein de réseaux de chercheurs regroupés de façon thématique plutôt que par spécialité, réalisant ainsi une approche pluridisciplinaire et multisectorielle du développement.

La recherche fondamentale orientée doit aussi servir de véhicule à la formation des chercheurs et des formateurs dans leur milieu. Réalisée dans la région, elle permet une meilleure adaptation de la personne formée à son environnement et une fixation du chercheur dans son milieu. En outre, dans ce cadre, la participation à des réseaux scientifiques de collaboration Nord-Sud / Sud-Sud doit donner la possibilité au chercheur de faire des sorties ponctuelles pour une formation complémentaire de durée limitée, ou pour des échanges d'expériences.

Place de la collaboration internationale

La collaboration internationale doit jouer un rôle fondamental dans la promotion et le suivi de la recherche fondamentale en Afrique. Force nous est de reconnaître qu'elle est la principale source de financement de cette recherche en Afrique francophone sub-saharienne. Toutefois, cette collaboration ne peut se concevoir dans cette seule optique de bailleurs de fonds. La collaboration internationale doit être le catalyseur de la recherche fondamentale pour un développement rapide et harmonieux. Ainsi, sa place est primordiale auprès des pays de la région en instaurant un véritable partenariat pour :

- apporter un appui aux états pour le renforcement de leur système de recherche ;
- promouvoir la création de réseaux et d'équipes multinationales pour une collaboration en partenariat ;
- soutenir la promotion de programmes régionaux de recherche ;
- favoriser la reconnaissance de la contribution des chercheurs d'Afrique sub-saharienne à la recherche fondamentale internationale ;
- renforcer les systèmes de circulation des informations et de diffusion des résultats en Afrique francophone et dans l'espace scientifique francophone en général ;
- soutenir la formation des chercheurs de la région et à tous les niveaux ;
- renforcer les mécanismes de transfert du nord vers le sud de reconnaissance et de technologie par des investissements pour l'amélioration des infrastructures des pays de la région.

Conclusion

Je préfère ne pas conclure, j'attends vos contributions pour renforcer mon plaidoyer pour une promotion en Afrique d'une recherche en biologie moléculaire au service du développement et pour un mieux être des collectivités dont nous sommes issues.

Concluding remarks: a Latin American perspective

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In my concluding remarks I am supposed to speak as a Latin American scientist in the field of biomedical research and to provide an overview of what we have heard from the remarkable members of our panel and extrapolate it towards the conclusions that we want to come out of this Conference.

As a Latin American scientist, I feel confident that I represent the scientific community in our region in stating that we have an ambivalent feeling of excitement and concern. We are excited by the tremendous possibilities offered by the biological revolution. Biology is certainly poised to make a tremendous leap forward in our knowledge and understanding of the life processes. The book of life is open and we have learned how to read it. This book will reveal to us many wonderful mysteries that have been puzzling the human mind since it gained cognitive powers. This knowledge will be highly relevant to human health and will give us powerful tools to understand and combat disease. We are enthusiastic to participate, albeit in a small way, in this great intellectual adventure. We would like to be actors, not mere spectators, and to help to bring the benefits of this new knowledge to improve the quality of life of our millions of poor. And 'there's the rub', as Hamlet said – there rises our concern.

There is a lot of talk about globalization – of the economy, of information, of culture – and yet the great paradox is that the world is becoming more and more polarized and fragmented between the 'haves' and the 'have nots'. This great fracture, this great abyss, has ceased to be strictly geographical, a matter of North and South, because it now cuts across each of our countries, which are divided into the affluent and the miserably poor.

Obviously, in our countries, those of the so-called Third World, the matter is more serious because the great majorities are among the poor and the gap that separates them from the advantages provided by science and technology is despairingly wide. Science and the power of knowledge, while pursuing high ideals, are unwittingly helping to increase the gap because their products only reach the hands of the privileged.

What is the answer? Are we to stop research in the Third World and dedicate ourselves only to building primary schools and sanitation facilities, as some propose?

I hold that this would be a terrible mistake. It would mean giving up our future, accepting intellectual subservience for ever.

The answer is within ourselves. The societies in the developing countries have to put their best minds to reflect about the future opportunities and challenges, about the enormous changes that are coming through scientific advances and also about the main problems of our people, about their health, their education, their hunger, their aspirations.

The answer is that these serious studies and reflections should generate public policies and programmes that chart a course towards a better future: national policies which recognize that, to enjoy the benefits of science, a society must support science, basic science, that the pursuit of knowledge is intrinsically valuable in itself; national policies which also recognize the power of science and technology as a problem-solver; policies that define relevant topics, that call scientists to put their minds and their efforts to find ways to improve the quality of life of the people that need it most. Our countries in general have no such policies.

We scientists are not called upon to perform specific tasks but are often accused of doing irrelevant work. International collaboration can help tremendously, but it cannot define the priorities for the countries themselves. The only way that we can attain a stable policy that can produce fruits in the long term is to have it arise from within a social consensus that is founded on profound studies and wide discussions.

We are not saying that this process cannot be influenced externally. The ideas and conclusions from other countries can and should be considered. Personally I am convinced that South-South collaboration, specially within the geographical regions of the Third World, can greatly help scientific development and the necessary science and society dialogue. This is specially true because the scientific communities in each country are too small and weak to stand alone.

There is also a great deal that the global scientific community, the great majority of which belongs to the Northern industrial nations, can do for us and for the goal of bringing the benefit of science to the poor. One thing that is obvious, but no less important, is the training of our young people in frontier science. This training, however, has to be permeated by an ideal of service and mission that will drive those people to return to their countries to share their knowledge with others and work on the relevant problems of our people. We have to rekindle ideals and gain back for science the respect and admiration of our young. This is difficult to do in a world wallowing in a market economy.

There is, again, a great gap between need and demand in the marketplace. Hunger and disease in the shanty towns of Latin America are not measurable in the market place. A vaccine for malaria is not attractive as a business! The ethics that we teach our young scientists are of paramount importance not only to point to areas in which science applications can be perverse, such as biological weapons, but also to stimulate them to work in areas in which science can be the best way of loving one's neighbour.

In summary, the biological revolution that is now happening presents us with a promise and a challenge:

- a promise of a great, a quantum, leap in knowledge about life and living cells and organisms;
- a promise of advancing enormously in our understanding about the genetic bases of disease;
- a promise of generating new vaccines and treatments of infectious agents;
- a promise of developing new therapies and novel powerful drugs;
- a promise of improving the lifestyle of our ageing populations;
- a promise of starting to unravel the mysteries of the mind and the cognitive processes.

These great promises are tempered with a serious challenge of finding ways in which we can make the products of this new knowledge improve the health of the poor: the challenge to bridge the gap, to heal the fractures.

These conclusions must be similar to that of all other areas of science being reviewed at this Conference.

Our only answer is to restate our support for science – for its essential cultural value, for its powerful capacity to generate socio-economic development – but also to redirect science and technology to include the goals of social and ethical relevance. To meet the challenge, the two cultures must establish a dialogue and scientists and the political and moral leaders of society must work towards policies that can give science this new direction in the 21st century.

Thematic meeting report

Nicole Biros
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Focusing on the life sciences, the World Health Organization (WHO) panel noted that genetics has become the reference point for thinking about all biology and for future research. It stressed the importance of genetics for other sciences such as chemistry and ecology, and concentrated on the collaboration between those working on genetics and health. Health was defined broadly as the absence of disease and injury in individuals, and the opportunity for them to be well-nourished, enjoy a good physical condition, have access to clean water and live in a safe, comfortable and sustainable environment. The panel emphasized the importance of the mental and social aspects of health and well-being.

In this context, the panel explored some of the new and promising avenues which recent advances in knowledge and DNA-based technology are opening up for both individual care and public health. The areas considered included biologicals and vaccine development; surveillance and control of epidemics and new infectious agents; screening, prevention and treatment of gene-related diseases including hereditary disorders; new perceptions of ageing; and new approaches to disease and disability prevention and management. The panel made a systematic effort to balance opportunities and constraints in the light of current health needs.

In reviewing the main determinants of the biological revolution, the panel stressed the fundamental role played by basic research in biochemistry and genetics. It noted that advances in knowledge have also been led by a number of technological breakthroughs. DNA cloning and DNA sequencing have given researchers the ability to isolate various disease-related genes and study them at the molecular level. High-resolution cytogenetic techniques and *in situ* hybridization analysis have made it possible to identify genetic aberrations and map genes at the chromosomal level. It was also noted that the biological revolution could not realize its full potential without the computer revolution and the unprecedented capacity it has provided for carrying out complex analyses of vast amounts of data. All this led the panel to stress the importance for all countries of providing strong and sustained support to basic and applied research.

Access to data and information systems was seen as essential to the development of research and science education at all levels. It was pointed out that, while international cooperation should be mobilized to support the free flow and exchange of information, governments in all countries also have a major responsibility to ensure Internet connection at national level. The initial investment does not have to be high and would enable students and researchers to gain access to the huge store of information already available to the general public in journals and databases through the Internet.

The panel's presentations illustrated how advances in molecular and cellular biology over the last two decades have begun to help elucidate the complex mechanisms that underlie immunity, genetic disorders and the progression of various diseases. Discussions showed how a better understanding of the structure and pathogenecity of micro-organisms is a first and essential step towards novel and more effective preventive and therapeutic approaches. Thus, in 1982, an infectious agent, *Helicobacter pylori*, was recognized as an important factor not only in ulcers and gastritis but also in gastric cancer. Various proteins that contribute to its pathogenecity and virulence have since been identified. Similarly, having completely sequenced the 1.8 million base pair genome of *Hemophilus influenzae*, it has been possible to relate virulence to the lipopolysaccharides on its membrane. Based on such findings, research on effective tools and interventions against these diseases can be better targeted.

Genetics and DNA technology have enhanced the prospects of developing very sensitive tools for the prevention, diagnosis and treatment of disease. Studies have shown that drugs and vaccines prepared using DNA technology are often safer, more effective and easier to produce in large quantities than those produced by other means. Some of these recombinant (genetically engineered) drugs, such as erythropoietin (a hormone needed to prevent anaemia in patients with kidney failure) and factor VIII (a blood-clotting agent), have proved to be life saving. Without the use of DNA technology, some of these products could not be produced at all. One of the most interesting prospects is the possibility of individualizing treatment. It may be possible, for example, to tailor drug regimens to the specific array of genes associated with different cancers. For other diseases, it may also be possible to predict which of several drugs is likely to work best and with fewest side-effects in individual patients.

The techniques and knowledge of molecular genetics have major implications for the prevention and control of non-communicable diseases in general, including hereditary disorders. They make it possible to identify their genetic component, detect susceptibility and sometimes assess risk in individuals or families. The panel's discussion on cystic fibrosis showed how much ground has been covered since the isolation of the causative gene in 1989. Polymorphic DNA markers have been discovered, the gene has been localized, more than 800 mutations have been identified and related data have been made accessible to all through the Internet. Genotype/phenotype correlation studies are exploring the variability in the clinical presentation and severity of the disease against the wide range of gene mutations. Important practical applications of current knowledge include DNA diagnosis and testing for carrier status, newborn screening programmes and genetic counselling. A better definition of the mutant proteins and understanding of modifying factors will lead to improved disease management and alternative treatment.

The same rigorous, complex and time-consuming process described for cystic fibrosis can be generalized to research and development on other gene-related affections. These may be caused by defects in a single gene (e.g. muscular dystrophy, haemophilia and sickle-cell disease), by changes in somatic cell DNA (e.g. cancers), or again by a combination of inherited susceptibilities and lifestyles and environmental factors (e.g. cardiovascular diseases). It was stressed during the discussion that while expectations regarding gene therapy were high, it would take time to discover cures. In addition the costs involved in the whole research and development process meant that such treatments were unlikely ever to be cheap.

The panel considered some aspects of research on health problems such as arthritis and Alzheimer's disease, which are becoming increasingly relevant in view of the general ageing of the global population. It noted that, whatever the progress of science, increased longevity will at some point bring with it some measure of disability. The panel felt that while biomedical research must continue to help improve the prevention and management of disease, it is equally important that the people concerned should receive social and psychological support – from public policies, and from society as a whole. The panel expressed the same concern that mental health issues and the prevention of HIV/AIDS should be dealt with not just in the laboratory and in scientific terms, but within inclusive approaches that take into account the whole social fabric and recognize the right and ability of individuals and their families to help themselves with the support of the health professions, including researchers, and policy-makers.

This part of the discussion led the panel to two main conclusions. The first was that scientists should actively pursue their research to improve knowledge and practical tools against disease but that at the same time they should be social activists, pressing for appropriate care and social support to be provided to people living with gene-related conditions. The second was that the international community needs to explore new ways to ensure accessibility of treatment to poor communities and countries without discouraging development work. The panel emphasized that research on this question could be as helpful as the basic scientific work itself.

The discussion then focused particularly on the public health benefits of DNA-based technology. Surveillance through screening for DNA sequences which are unique to particular organisms or their variants was reported as being faster and more reliable than through conventional methods. This has important implications for ensuring the safety of blood products, foodstuffs and drinking water. DNA 'chips' could also be used to detect potential threats from bioterrorism. More generally and of immediate interest to public health, DNA-based technology can greatly facilitate global surveillance of infectious diseases, drug resistance – including resistance to antimicrobials – and the emergence and potential virulence of new micro-organisms such as HIV, Ebola-type virus and A(H5N1), linked to the recent 'chicken flu' outbreak in Hong Kong. The panel noted that international cooperation and Internet networks for such data already exist. It stressed that, to be effective, such surveillance networks should achieve worldwide coverage and be able to rely on researchers and health workers with appropriate expertise and training in all countries.

An important point in the panel's discussion was the need to reassess research priorities and the potential benefits of DNA-based products and treatment methods in view of the scale of global disease. The panel noted with concern that an estimated 10% only of the funding of research is dedicated to the pathologies and problems that affect 90% of the people of the planet. It considered it both a moral and a health imperative that optimum use be made of the powerful new DNA-based technologies to prevent and control health problems that are major causes of morbidity and mortality throughout the world, especially in developing countries where the potential benefits would be enormous.

Health statistics suggest that safe and effective vaccines for the prevention of infectious diseases are the most pressing global health need. At this stage, the development of novel vaccines is critically dependent on DNA technology. As emphasized during the session, if safe and effective DNA-based vaccines can be developed against infectious diseases such as diarrhoeal diseases, malaria, acute respiratory infections, tuberculosis and HIV/AIDS, the lives of 8 million children a year could be saved. Since the infectious disease burden is greatest in developing countries, it is essential to make such products accessible to these countries.

Particular emphasis was placed on the need to help develop market studies and gather evidence on the economic viability and long-term social and financial returns of research and development on ‘orphan’ drugs and vaccines. This was discussed in relation to research on infectious diseases such as malaria, tuberculosis and HIV/AIDS, which is confronted with a complex combination of market-related problems and technical hurdles such as virus variability, variations in host responses, inadequate animal models and poor understanding of protective immunity. Shigellosis, an enteric disease which claims the lives of about 700 000 children every year, was also discussed at some length. The main technical problems appear to be solved, several very promising candidate shigella vaccines have been developed, but uncertainty remains as to the extra funding needed to complete the process and move on to clinical trials. WHO reported how it had been possible to demonstrate that, while the poliomyelitis eradication campaign was costing US$ 500 million a year, eradication once completed would produce savings on immunization, treatment and rehabilitation costs of the order of US$ 3 billion. The panel recommended that similar data be systematically gathered and publicized for other areas of health research and interventions.

Discussants gave examples of specific policies and measures which, in different economic and social circumstances, had proved successful in their own countries. These included public policies for strengthening science education for all, setting up trust funds for research and innovation, and launching several genome research projects at national level. To promote research in developing countries and prevent ‘brain drain’, experience showed the importance of building up institutional research capacity and encouraging in-country training. The group stressed the urgent need to develop human resources and train researchers in developing countries not only to enhance their own human and scientific potential but also to contribute to increasing and diversifying our global store of knowledge of the life processes and the specific traits and health problems that may occur in diverse environments worldwide.

The discussion on Africa’s needs and expectations regarding the biological revolution led to some very practical and challenging observations. It was argued that what is needed is the building up, in African countries, of a critical mass of researchers and scientists who can work as teams and ensure continuity in the work done. They should also have the opportunity to use their skills and knowledge in their countries and exercise their profession with some measure of stability in research institutions of good technical and scientific standing. This would give nationals a real chance to define and carry out research in accordance with local needs, constraints and priorities, as an integral part of the country’s overall development effort. It would mean research would have to be sustainable. It might also mean choosing original directions for basic research. It would in any case require that research efforts be reorganized according to action themes rather than compartmentalized by disciplines as they are at present.

While reviewing some of Africa’s experience of collaborative research on issues such as sickle-cell disease and hepatitis B, the panel heard about the high level of hope and participation which such research had originally elicited from African scientists and local communities. This, however, had given way to frustration and loss of confidence as both researchers and communities found they would not have access to the data, products and therapies they themselves had helped to produce. The panel recognized that, in the end, the legitimacy, credibility and usefulness of science would depend not only on the quality of research and its outputs but also on the scientists’ own behaviour and ethics, and on their ability to acknowledge and understand the needs and concerns of others.

In developed as in developing countries, the communities should be informed and consulted, and their perceptions and expectations taken into account by those who fund, define, carry out and implement research. For the dialogue between scientists and the general public to be truly meaningful and well informed, it is equally important that science education should be accessible to the greatest number possible. The same ethical and democratic principles that generally apply to life in society should also guide scientists’ behaviour and relations with others. Patients and human subjects in research should not be seen as a means to an end but recognized as the ultimate beneficiaries of research. In conformity with principles of ethics and fairness, they should be guaranteed access to personal data, products and treatments which have been developed thanks to their participation in epidemiological and clinical research. Similarly, mutual trust, respect and sharing of data and responsibilities should guide relations and collaboration between researchers from developed and developing countries. The international research community could best demonstrate its commitment to promoting science and equitable partnerships with researchers in developing countries by supporting the development of national centres of excellence in those countries and their networking at regional level.

To ensure a better distribution of research efforts and a more equitable access to science and its health benefits worldwide, the WHO panel called for commitment to specific policies and actions and their urgent implementation. It proposed the following recommendations:

- Governments should provide stable financial commitment of at least 1% of their gross national product (GNP) to research and training. They should define sound and comprehensive national research policies, set socially relevant research priorities and in particular strengthen basic biomedical research. They should establish guidelines and regulation on biosafety and work towards their harmonization at international level. They should also promote research and social support programmes for mental health and the ageing population.
- UNESCO should intensify its support for the training of young scientists in developing countries in the area of molecular biology and genetics, in particular by supporting the development of South-South and North-South cooperation networks. It should continue to lead public and multidisciplinary debate on ethics and science.
- WHO should promote basic and applied research and cooperation on DNA technologies, to help reach a better understanding of the genetic basis of disease and develop beneficial applications for health care and the enhancement of water and food supply and safety. As a matter of priority, it should support the development of vaccines and other biologicals for the control of diseases of public health importance in developing countries, such as hepatitis B, HIV/AIDS, malaria and shigellosis, and ensure that these biologicals can be accessible at affordable costs to those who need them most. As recommended to the World Health Assembly, an integrated genetics resource centre should be established within WHO to support countries in obtaining access to relevant knowledge and information, and in developing appropriate policies, training and health services in this field.
- The scientific community represented by ICSU, the academies and other institutions should ensure that scientists from all countries have free and open access to scientific knowledge. It should assume its social and ethical responsibilities by mobilizing all its members to tackle problems which are priorities for the health and welfare of the poor, and for the safety and sustainability of our global environment. It should establish a dialogue with society in order to clarify ethical issues arising from scientific knowledge and promote the peaceful use of science. It should uphold and put into practice values such as compassion and respect for the dignity and rights of all fellow human beings.

Biotechnology: a new input to agricultural research and food security

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One of the major problems arising in modern intensive agriculture today lies in the high degree of pollution produced by the use of herbicides, pesticides and fertilizers required to obtain high-yielding crops. This problem is already on the table in many sectors of society and the conclusions of this session could contribute with recommendations on how to proceed in the future and how science can help to tackle this major problem.

While agriculture in industrialized nations has become intensive and pollutant, in developing countries it is still based on extensive agricultural practices. In fact, scientific and agricultural research have not made enough progress and given rise to enough applications to foster intensive tropical agriculture; therefore, a greater land area is being absorbed into agriculture, while only marginal lands with low soil fertility but a high degree of biodiversity are left and risk disappearing.

This biodiversity can be seen in terms of plant and animal diversity and, for scientists, it is a huge reservoir of biochemical diversity containing interesting components that we are losing. It is therefore necessary to acknowledge that, while we are not adequately addressing the challenges posed by agriculture, we are at the same time losing a wealth of biodiversity.

The major industries involved in scientific research have decided that they can no longer rely on pollutant agricultural protection schemes. This means that, in future, we will have to rely on plants themselves for their protection. Industrial companies are aware that society will no longer accept pollutant agriculture and most of the major chemical companies have decided to reprofile themselves as a biotechnological industry. There will be a boost in research based on plant molecular biology and hopefully it will also be applied to tropical plants, because the industries will realize that agriculture in temperate and tropical areas needs to be taken into consideration.

During this Conference, stress was laid on population growth. Fifty years ago the world's population counted 2 billion people; now there are 6 billion. Population growth is a social and economic problem which implies a redistribution of wealth and food as well. Science and scientists are called upon to face this challenge too.

In order to contribute to agricultural production in quantitative and qualitative terms, many achievements in agricultural research will need to be fostered – hybrid yield, drought resistance of crops, better protection against pests – while adopting better agricultural practices that do not pollute the environment. Creating an industry that contributes to sustainable agriculture may seem ambitious, but industry relying on better use of natural resources is possible.

In the 21st century, 90% of the world population will live in developing countries. Therefore, besides food security and environment, health needs to be addressed. Can research be done on the use of plants in order to have cheaper sources of medical care? Is it possible to produce vaccines, antibodies for clinical analysis that are cheaper? In fact, the population in developing countries cannot always afford industrial medicines and medical care schemes.

How do we proceed in this research in relation to tropical agriculture? Based on the experience gained in the past, basic research is indispensable. The use of molecular biology and the making of novel plants requires research. Who will carry out the research in developing countries? One solution could be to use the industrialized countries' experience in genetic engineering. The Consultative Group on International Agricultural Research (CGIAR) centres may work together with universities and design projects that include those industries, because they are necessary for commercializing products efficiently. How could industrial improvement be stimulated in harmony with the needs of the population in the developing countries?

Moreover, it is necessary to consider public opinion and acceptance of new technologies. On the basis of the tests and controls carried out in the last 15 years, scientists say they have not found risks for food, health and the environment. How can scientists better communicate and inform public opinion when it expresses its concerns? Can scientists become the promoters of this dialogue with the public, leaders of industry and policy-makers who share the same concerns? Consumers must be aware of the advantages of biotechnology.

As industry advances in biotechnological research, the incentive for companies is to increase commercial revenue and establish themselves as a powerful industry. Society then needs to negotiate as it did in the 19th century during the Industrial Revolution, in order to benefit too from industrial advances. How can this be achieved? Are current institutions and structures capable of carrying out this negotiation with industry?

On the one hand, social concerns related to biotechnology are expressed by organizations like Greenpeace, which is opposed to the use of genetically modified organisms in food production and to patenting of living organisms used in biotechnological research. On the other hand, industrial research requires prototype products to start a company (for temperate or tropical crops) then it has to negotiate for registration in order to commercialize the product.

The case of the *Arabidopsis thaliana* plant illustrates how fundamental research works. This plant is a crucifer, very close to the *Brassica* species and is commonly known as rapeseed. Currently scientists know almost the entire DNA sequence of this plant, although some companies already have the full sequence and in the year 2000 it will be available in a database. Because plants function with at least 20 000 genes and this plant has one of the shortest DNA sequences and fewer than 25 million base pairs, 60% of its genes are already known and the rest will be known by the end of the year 2000. These findings allow us to move on to the next step of knowledge-building. *Arabidopsis thaliana*'s genes are exactly the same as in other plants; therefore the identification of its DNA will enable the identification of genes in other plants.

The use of molecular biology can be extremely useful in understanding plant physiology. By applying fundamental genetics, it is possible to create tailor-made mutants which can help to understand better how physiological processes work in plants. For instance, instead of a flower, you may have the cauliflower mutant, which is a proliferation of meristems, that can show how a cell divides and which compounds are made in such meristems, for instance, hormones that are still not known.

An example which can illustrate the use of molecular biology and genetic engineering as a tool to better understand plant physiology is RNA messenger pattern profiling. Such profiling could be done by examining the replicated cells and therefore deducing an inventory of the 2 000-3 000 proteins that are usually present in any plant physiological process. But even more important is the possibility of making metabolite profiling, both the solutes and the volatiles. Microfilters for the messengers can be made and with two or three filters it is possible to progressively identify the RNA messengers that correspond to each and every gene of a plant. Such research is being carried out with poplar trees, a plant that has never been used for genomic analysis; analogous ways can be used for any plant.

It is known that many of the chemicals currently used are originally plant-derived and many of the new chemicals will be found in plants through the study of secondary metabolites. For example, taxol, a plant-derived chemical compound used in experimental studies against cancer, cannot be industrially synthesized because the process is too complicated and expensive. But once scientists are able to use the molecular biology tools already mentioned, they will be able to decipher the physiological processes of the plant and it will be possible to identify the biochemical pathway. Many of these plant-derived chemical compounds are of importance for human health and for the pharmaceutical industry.

Molecular biology research can be applied, too, to the protection and conservation of biodiversity by showing the uses and value of products for the well-being of humankind. The value and uses of products may be an incentive for developing countries to save their forests. The USA itself is unable to put a stop to the felling of sequoia trees (*Sequoia gigantea*) that are 1 000 years old; timber companies are continuing to fell them because legislation and policies allow them to do so. Countries like Brazil may find more incentives to save the Amazonian forest with help from scientists to prove the value of forest plants. While the forests may have an academic value for biologists, countries which need more economic revenue may find that commercial products derived from them are of enormous value.

For example, with the help of the European Union, prospecting is being conducted on what is left of the Atlantic rainforest around Rio de Janeiro and the Amazonian forest, in order to identify what biodiversity is left and find the best trees for reforestation of depleted areas. In this case, DNA fingerprinting, applied for instance to leguminous trees, helps recognition of each species and even individual trees within a species. It is therefore possible to identify the parent tree growing 500 metres away from an individual and learn more about pollination and, to a certain extent, about the ecosystem of the forest and how it has evolved, to understand what happens in depleted areas subjected to reforestation. Molecular biology can therefore contribute to improving knowledge of forest ecosystems.

What can biotechnology do to identify new plant products for agricultural production? With the help of DNA fingerprinting techniques, it is possible to trace genetic maps of plants that have never been used in breeding. It may be possible to identify fruit trees growing in the forest that are currently not used. Those fruits are probably only used by local populations because they cannot be transported but, through breeding and with the help of DNA fingerprinting, it is possible to grow them for commercial production. A concrete example of application of molecular biology to plants which have not been used for breeding comes from a temperate forest. This is the case for poplar trees, where research may lead to a better quality of wood, mainly because of the increasing importance of lignin and cellulose products for industry.

In more specific terms, single sequence repeat patterns used to identify the genes of a plant may be used to make quantitative trait loci (QTL) 'libraries'. These libraries, which contain information for instance on poplar trees, can be used to identify the genes and analyse what characteristics are worthwhile for plant breeding and use the candidate genes for predominance to improve disease resistance of the trees. In the case of poplar trees, it was possible to engineer trees that had a better separation of cellulose and lignin.

To conclude, there are many other applications of molecular biology and biotechnology which may benefit countries in tropical regions. For instance, the kind of research carried out in the USA with the Bt toxin that produces insect resistance in corn (against the stem corn borer) has a lot of applications: for breeding insect-resistant cotton, which makes harmful chemical applications less necessary, or in order to obtain hybrid vigour in plants.

This kind of fundamental research at international level will require the creation of networks with all universities in the Western world where scientists are willing to cooperate with developing countries. The role of the CGIAR research centres may be to set up the prototype products, followed by agreements with industry to conduct and apply research in harmony with the interests of the different countries.

Creating a global knowledge system for food security

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The US National Academy of Sciences is a public service organization. Since our inception in 1863, we have been charged by our Government to provide advice to the nation and the world. We now have about 6 000 volunteers at any one time providing science policy advice to our Government and other institutions, and they produce an average of about one report every working day. We make our advice freely available by publishing the full text of our reports on the World Wide Web for everyone to access. By using the search engine provided, anyone in the world can have access to our research reports on water, soil, education, and so on.

I am a scientist and I would like to address an important question that Professor Van Montagu raised: how can scientists from around the world be better connected to the problems of food security? This is a problem that I had time to investigate as part of a major study sponsored by the World Bank and the Consultative Group on International Agricultural Research (CGIAR) last year; in fact, it is from that experience that I learned nearly all that I know about the subject.

Science works by the sharing of knowledge and combining it in unexpected ways. We have a situation today where most young American scientists know nothing about the problems that we are talking about here today. They have had no exposure at all to the needs of most of the world's population and they know little about what is happening in developing countries. Most importantly, they have no idea of the many ways in which the science that they know could be of use to scientists in those parts of the world that are very different from the USA. And I am convinced that, if they knew more about developing country needs, they could be major contributors to those countries. Thus, the major theme of my talk is: how might we best connect the scientists in industrialized countries to the needs of poor rural farmers from around the world?

One type of report that we have on our website explains to the public how science works and makes the point that random collisions between various kinds of knowledge have led to major advances in the past and will create much of the progress in the future (see http://www2.nas.edu/bsi). We need to therefore create a situation where there are many more accidental (as well as planned) encounters between the scientists of the industrialized world and the activities, needs and scientists of the developing world.

We are making enormous progress in nearly all fields of science and it is all because we build constantly on the work of others – for example, by finding out about a powerful new technique that a scientist developed for some other purpose that we can apply to our own work. Science advances by sharing knowledge and creating new opportunities in unexpected ways. The challenge is to discover how we can do that much more widely throughout today's world, taking advantage of the revolutionary new communication technologies that are available.

During 1998, I spent about six weeks working on the CGIAR report and visiting various CGIAR centres. Part of that time was spent in far western Kenya, near the shores of Lake Victoria, looking at the on-farm research being carried out jointly by the International Centre for Research in Agroforestry (ICRAF)/CGIAR and KARI, Kenya's national agricultural research system. That experience profoundly affected me. I realized that there is no way we can meet the real needs of these farmers when we are so isolated from those needs. We have no connection in the USA with their problems of soil, plant diseases, etc. But if we could develop meaningful contacts with them, many of us would like to participate.

Our report on the future of CGIAR, released in October 1998, called for a major effort by CGIAR in genetic resources, for integrated gene management and an integrated worldwide programme on natural resource management, which is actually a more difficult issue involving the sustainability of agriculture, inputs, soils, water and output pollution caused by agriculture (see http://cgreview.worldbank.org/cgrevrep.htm).

Yet what we saw while visiting Nairobi is that there are hundreds of different agencies working on agriculture in Kenya. When we went around, we discovered that most of them did not know what the other ones were doing, creating a totally uncoordinated effort, with many of them 'reinventing the wheel'. Far too much effort has been invested in top-down projects. For example, somebody sitting somewhere in the USA might invent what he thought was a good idea for Africa; then in order to get funding from the US Government, he would have to find an African partner to carry out a project that does not necessarily meet a major need of the Africans themselves.

One of the recommendations in our report focused on the need to have much more local and regional involvement in research planning and the design of agricultural experiments. The purpose is to avoid top-down projects and have more coordination and bottom-up contribution from the African researchers and farmers.

In the USA we talk constantly about 'bringing science into the lives of all Americans': this is one of my Academy's major themes. Perhaps what we need internationally is to bring science into the lives of all the world's citizens. But how? We have been trying to get more science into the world's agriculture for a long time. Nevertheless, in many nations there has been little progress.

As a scientist, whenever you hit a hard problem – after banging your head against the wall for a long time – you jump to exploit any new tool that is developed that might help you. One of the new tools that needs to be much more intelligently applied to agricultural needs around the world is the wonderful new communication tool of the Internet and the World Wide Web. In our CGIAR report, we recommend the development of a Global Knowledge System for Food Security. This system would be designed to create a new two-way communication process between all the scientists around the globe and the needs of agricultural extension services, farmer organizations, villages and others.

A second powerful effect on me, besides my visit to Africa, relates to my visit this past January to Dr M.S. Swaminathan, in Madras, India, where I visited a remarkable experiment that he calls the Information Village Programme. About half the families in the rural villages that he is working with have incomes of less than US$ 25 a month. The project is designed to provide these villagers with knowledge that meets their needs using the World Wide Web.

The process starts with volunteer teams that visit the villages to find out what kind of knowledge the farmers want – not to tell them what they are going to get, which is the way too many of us work in the developing world. Particularly popular are information and advice on growing local crops; protecting crops from insect and other diseases; having access to daily market prices for these crops; and local weather forecasts. Also popular is clear information about the many government programmes that are designed to help the Indian poor, which are usually not accessible to them. Those villages that participate in this programme must provide a public room for the computer system. They also provide the people to operate them, mostly high-school graduates, who frequently turn out to be women. In return the village receives the hardware, the wireless communication system and specially designed websites in their local language.

Inspired by these two experiences in Kenya and India, and my 30 years of prior experience in American research universities, I would like to challenge us to work together to develop the Global Knowledge System for Food Security recommended in the CGIAR report that I mentioned earlier. Can we begin to do the experiments we need to work out a communication system that connects scientists and farmers in a way that empowers the farmers with knowledge to improve their livelihoods, while making the scientists much more aware of developing country needs?

The system should be based on a global network established on the World Wide Web. The basic idea is to start with an international database of the best available scientific and technical knowledge organized in a readily accessible form. We do not really know how to do this yet, to get this massive amount of information on the World Wide Web in a way that can be useful to the many people who would benefit from it in the developing world: the national scientific organizations, universities, non-governmental organizations (NGOs), the farmers' organizations, women's organizations and the villages. A critical aspect of the system would be learning how to establish meaningful two-way communications, because, unlike television or radio, the Internet readily allows for this possibility.

While assessing from villagers what their needs are, we should try to analyse and compile the best of their indigenous knowledge, so that it could be readily spread to other villagers elsewhere in the world. Instantaneous two-way communication on the Internet thereby provides a great opportunity to do something we could never do without this wonderful communication device.

Our Academy would like to carry out an experiment in which we partner with a few developing countries. The purpose would be to develop a prototype website that would make available the relevant scientific and technical information, on a narrow range of issues, in a form that is most usable by the clients. We need a partner to help us figure out what exactly would be useful to some regions of Africa, for example. When we were travelling around to visit the different CGIAR centres, we saw all kinds of wonderful publications that had been designed to help local farmers. Over the years, many things have been designed that are very useful, but they are generally inaccessible to most of those in the world who need them. How can we get all this material onto the World Wide Web so that the best designed material for local farmers in Kenya (for example) can be available to local farmers all around the world, and so on?

From our side, in the industrialized nations, we have begun to do a small part of the work. For example, the US Academy publishes the *Proceedings of the National Academy of Sciences*, which is a prestigious scientific journal with more than 10 000 pages published per year. Our decision has been to make the World Wide Web version available free of charge for scientists throughout the developing world. This is one way that we can easily contribute.

Even more importantly, about a year and a half ago, the US Government, through our National Library of Medicine, decided to make the major search engine for the biomedical literature freely available on the World Wide Web. Now anybody in the world can have access to the abstracts, at least, of most of the world's biomedical literature at http://www.ncbi.nlm.nih.gov/PubMed. It would be good to have the same kind of search engine freely available for agriculture and the environment, because an effective sharing of knowledge with the developing world is only possible if people do not have to pay exorbitant prices for it.

I would like to end by challenging the CGIAR to make an annual list of the 100 most important scientific challenges in agriculture for specific areas of the developing world and advertise it for all to see on the World Wide Web. In this way, we could quickly jump-start a worldwide effort to engage scientists in the challenge of meeting the real needs of local farmers everywhere.

Science and agriculture: mobilizing society for food security

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The world is currently facing the greatest population explosion in history, with the most rapid population growth occurring in developing countries. Food production has not kept pace with the increase in population and would need to expand by at least 2.5% per year in the coming decade to provide for the fast-growing hungry populations of the world. The alarming question is: will we have the means to avoid a growing threat or will we be struggling in the new millennium to feed hungry populations and avoid malnutrition and food shortages?

Agricultural technology for exploiting the presently non-arable lands is a long way off. Most developing countries struggling to increase agricultural production need to do so on land already under cultivation. Green Revolution technologies and the policies used to promote them and sustain their efficient use may prove to be inadequate for further growth in production.

The regional food security problems that Third World countries have encountered over the past century have undoubtedly been alleviated by the contributions of the Green Revolution since the 1960s. The causes of the production deficit include:

- inappropriate technology;
- limited land;
- decreasing water supply;
- environmental degradation;
- inadequate research;
- fossil-fuel energy constraints;
- inappropriate post-harvest handling and storage; and
- unpredictable weather;

in addition to:

- population growth;
- rising affluence; and
- inequitable social and political structures.

The Green Revolution transplanted a range of agricultural technologies from the rich to the poor countries. Agricultural techniques today are numerous and range from the conventional and traditional scientific techniques to the complex genetic engineering. With the help of new improved seed strains, fertilizers, better practices, mechanization, improved irrigation efficiency, integrated management techniques and reduced post-harvest losses, crop yields have increased in many countries, especially in Asia. As a result, the real price of staple foods has dropped, which in turn has helped to boost living standards in many countries. Indeed, without the Green Revolution, the number of ‘absolute poor’ would have been higher by some hundreds of millions.

Unfortunately, countries in desperate need of modern techniques were only exposed to and allocated technology ‘left over’ from the industrialized countries. This has in effect deepened the dichotomy and broadened the gaps between rich and poor and the industrialized and Third Worlds. Further, a lack of appropriate education, of the capital and the infrastructure to fully develop and absorb such technologies adequately, Third World mismanagement and lack of technical know-how have caused environmental damage and jeopardized natural resources.

The water shortage in certain regions, coupled with soil degradation and the advance of deserts, changing climate, global warming, the ozone hole and a rise in CO_2 concentrations, makes it hard to foresee a sustainable level of agricultural production. Historically, conventional sciences have increased agricultural output of rural societies through integrated management techniques, the use of fertilizers, water management techniques, planned land exploitation, etc. Today, better techniques through advanced cell and atom research are available to us. This biotechnology technique may be capable of serving a globally fast-growing population.

Agricultural biotechnology is multidimensional and similar to other technological innovations. It should be looked at from several different perspectives including economics, sociology, management science, history, etc. The benefits of biotechnology in terms of the positive impacts on agriculture are nevertheless numerous. Some of these are:

- crop improvement directly improves product quality;
- improved nutritional value helps alleviate undernourishment in the world;
- increased yields and productivity;
- less water and land use;
- improved resistance to pests, diseases and weeds;
- substitution of one crop for another;
- adaptation of existing crops and livestock to different environments;
- sustainability and environmental protection;
- maintenance of variability and biodiversity.

While tissue culture and immunological techniques can be easily integrated with traditional agriculture without causing any ethical or health hazards, other areas of biotechnology such as molecular genetics and recombinant DNA, or aggressive biotechnology, have far-reaching repercussions that remain unclear. The consequences of introducing ‘foreign genes’ into food consumed by humans are unknown. If a gene-manipulated plant is crossbred with other varieties, a detrimental variety might be released into nature and have adverse consequences. An illustration of uncontrollable outcome is the escape of the African killer bees being studied in South America that have already invaded the southern states of the USA. Another example is ‘mad cow’ disease. This was successfully tackled by Western developed nations; however, what would be the repercussions of a similar crisis in the Third World? How soon would the problem be spotted, how effective would the appeal for help be and how swiftly would the problem be resolved? All these issues are of utmost importance and reveal the inadequacies of technological infrastructure in absorbing potential problems were these to arise in Third World countries.

Considering the risks of reactions, allergies and other effects of such genetic manipulation, the adoption of aggressive biotechnology should not be allowed to proceed until society acquires a better understanding of the science. Our focus is to make sure that biotechnology remains a food security investment, rather than a burden on those already put at an earlier disadvantage.

From a legal standpoint, proper legislation is necessary for the introduction and release of any new technology. Obtaining patent protection on unique new plant varieties is relatively straightforward, while patenting transgenic animals and microbes is still difficult. Certain conventions have already been held and issues discussed. Specifically, various countries have ratified a number of agreements relating to biodiversity and biosafety, drafted mainly by the Food and Agriculture Organization of the United Nations (FAO). However, the main issue remains of patent matters relating to use of the invention rights by the Third World. Can the Third World afford to use the intellectual property rights relating to biotechnology? Evidently, the underdeveloped world does not have the adequate resources and means to purchase the scientific solution to their problems.

Transfer of technology now seems to be the only way out. This can only be served through the mobilization of society through capacity-building, reforming institutions and the adoption of a new development paradigm. Shouldn’t science, at a crucial point, be taken up by transnational public organizations for the benefit of all and isn’t knowledge after all a public good? If it is not a legal matter, it is at least an ethical must, for the development of all humanity, indiscriminately. Otherwise, the underdeveloped will remain and the gap will only widen.

Only a few countries own the factors of production, resources for invention and research industries. They have invested time, funds and their workforce in scientific research. But that should not mean that it is the rich and developed countries that should decide which areas of agricultural biotechnology research are to be focused on. Private research companies have been granted patents for the ‘Terminator’ seed technology, among others. Biotechnology can turn into a profitable business for the five major modified seed companies or ‘gene giants’ at the expense of the Third World if governments and international agencies do not intervene.

The invention of ‘Terminator’ and ‘Terminator II’ has put farmers in an arduous position. The ultimate objective of agri-business has become to force farmers to pay for seeds every season. Although poor farmers in developing countries grow 15-20% of the world’s food and directly feed at least 1.4 billion people, they are nevertheless poor and cannot afford to buy seeds yearly. Those farmers depend on both their saved seeds and their own breeding skills in adapting other varieties for use. Needless to say, conserving and selling seeds constitute a significant proportion of that farmer’s income.

Most of the research on biotechnology is privately funded and hence aggravates the problem by being profit-oriented. Gene giants are not interested in developing plant varieties in favour of poor farmers who lack the financial means. The focus is mainly on high-yielding irrigated lands. This leaves resource-poor farmers to fend for themselves. Poor farmers are in effect marginalized by developments in agriculture.

It is a fundamental right of farmers to save seeds and breed crops. Whatever advances have been made up till now have only been possible thanks to those farmers who saved the seeds from their harvest for millennia and who preserved the viability and diversity of these.

National and international legislation has only come to favour the very latest biological invention increments belonging to the developed world and has disregarded rightfully owed past acknowledgement of the chain of inventions that were instituted by those farmers who maintained the original germplasm.

Can we distort nature to abate a looming food security crisis? If the outcomes are not as promising as we would wish them to be, will the changes to the ecosystem we will cause be reversible or will the damage be terminal?

The impediments to proper global integration in the biotechnology era ought to be efficiently resolved. First and foremost, governments should increase investments in basic education because of increasing knowledge gaps between developed and developing countries. Without some form of properly guided education, technologies in any form cannot be absorbed. Special attention should be paid to women, who represent the major food producers in developing countries and who, if provided with basic education, could help raise agricultural productivity and income through adequate use of the new technologies. Additionally, and for the purpose of raising productivity, the time has come to invest heavily in agricultural research and extension in developing countries.

Information services in remote areas are a critical concern. Farmers ought to be aware of environmentally sound practices in order to maintain and preserve the natural resources. Information can be transmitted either through local radios, participatory videos, printed materials, the Internet or through telecentres. Information exchange facilitates agricultural development by giving a voice to those involved, namely the farmers. Governments could empower farmers by giving them more resources and political autonomy, improving access to markets and developing funding channels for the rural population. Foreign investments may also be needed because of limited national funding.

It is of extreme importance that governments develop clearly defined objectives and outline a strategy for technology in the agricultural sector to enhance productivity in the rural and food sectors. Governments are nevertheless not alone in their struggle. Food security is, and will remain, a global concern and governments must not act alone, but rather incorporate partners and form alliances in order to accomplish crucial objectives. The Consultative Group on International Agricultural Research (CGIAR) is combining its efforts with developing countries and ensuring that biotechnology is ‘needs-driven’ rather than ‘science-driven’. National Agricultural Research Services (NARS) should also play a role in using the advances made in biotechnology to benefit the poor. Collaboration with non-governmental organizations, agricultural research institutes, the private sector and universities or public research institutes is necessary.

If progress is not achieved rapidly in the poor regions of the world and if basic food needs are not met soon, all countries stand to lose. Biotechnology should be integrated with traditional agricultural methods and agricultural research should be directed towards the farmers’ needs in developing countries.

Since food security is a global issue, efforts to mobilize societies, consolidate activities and safely channel the fruits of technological breakthroughs are the only way in which we can avoid the ‘misdistribution mistakes’ of the Green Revolution era. On the eve of the next millennium and learning from the lessons of the past, exposure – and most importantly accessibility – to any scientific advance ought to be considered a legitimate right owed to all. The facts are disturbing, the needs urgent and the means available, so let us work together and strive for a hunger-free world.

Thematic meeting report

Enrico Porceddu
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The present thematic meeting was jointly organized by the Consultative Group for International Agricultural Research (CGIAR), Food and Agricultural Organization of the United Nations (FAO), International Council for Science (ICSU) and the Government of Italy. It was held at the University of Horticulture and Food Industry, Budapest, and was chaired by Mr Ismail Serageldin, Chairman of CGIAR. The session was well attended, with 150 participants in addition to speakers, discussants and conference representatives.

Objectives

The objectives of the World Conference on Science were to analyse where the natural sciences stand today and where they are heading, what their social impacts have been and what society expects from them. The Conference sought to identify what efforts are needed to make science advance in response to these expectations. More specifically, the present thematic meeting on Science, Agriculture and Food Security was aimed at reviewing the contributions of science and agricultural research to agriculture and food production, examining the drawbacks accompanying the application of science and assessing its potential to meet challenges in the future.

Organization and structure

The session featured presentations by three speakers, commentaries by four discussants* and questions from the floor in an interactive mode. The session concluded with summing up remarks by the Chair.

Presentations and discussions

The presentations covered the following themes:

- Need for sustainable use of natural resources to provide food for an ever-increasing population.
- Promoting investment in basic research, especially in light of the track record of innovations and technical advances stemming from such investments (e.g. new crop varieties, improvements in the management of natural resources, expansion in the cultivation of elite cultivars engineered for specific traits and the promise of further developments). Public acceptance, an entrepreneurial attitude and continued investments were felt to be the key.
- Involvement of social scientists and public decision-makers in agricultural development, particularly to ensure that the new technologies being developed are suited to the needs of specific regions.

*For full text of presentation by discussant Prof. Gian Tomaso Scarascia please click here.

- Exploiting new communication tools for bridging the enormous 'knowledge gap' between developed and developing countries, and responding to the particular needs of small farmers in developing countries.
- Role of the international agricultural research centres (IARCs) of CGIAR and their efforts to promote suitable agriculture, enhance food security and reduce poverty by harnessing the best of science (e.g. conventional breeding, genetics and sound management of natural resources).
- Recognition of the fact that growth of agricultural productivity is unevenly distributed and that there is a real threat of food deficits for some areas; food needs in developing countries could nearly double over the next generation.
- Addressing the social dimension of agricultural development is important; innovations have to be blended with institutional reforms in a new development paradigm, where North-South cooperation is coupled with South-South coordination, and problems of small farmers are taken into account.

Discussants put emphasis on:

- reducing the gap between potential and actual yield by addressing issues related to biotic and abiotic stresses, particularly those that are not of interest to the private sector;
- the need to combine plant biology and biotechnology with natural resources management;
- the need to change or improve local and regional conditions, focusing on the prevailing economic, ecological, social and technical constraints of food deficit countries and regions;
- the need to harness the talents of young scientists educated abroad in solving local problems;
- the need to stimulate and integrate the local scientific communities into international efforts;
- the need to progress towards an environmentally and socially sustainable lifestyle, paying due respect to human and environmental rights and equity;
- the need for scientists to be conscious of the moral and ethical dimensions of their findings and their subsequent applications;
- the need for an ethical dimension in science and technology systems, one that is concerned with the common good, engages public opinion and promotes trust in society.

The following remarks were made from the floor:

- Scientific development is key to addressing the complex issue of food security, although adequate policies and other factors also play a role. Food security can be considered at different levels (household, community, national, regional, and global). Food security means access to food and includes food availability in quantity and quality to supply human needs for a healthy and productive life. Research is needed to create a better scientific understanding of the biological, physical, economic and social constraints as they affect food security, particularly in the context of developments in biotechnology and informatics; potential negative environmental effects of the new technologies; spatial, temporal, economic and social dimensions of poverty, and food availability; and public perception and acceptance of scientific innovations.
- Science-based solutions will have to be developed to meet the food and nutritional demands of the world's population in the next century. They should be based on environmentally friendly options for the intensification of complex farming systems at smallholder level. Soil and water are basic for agricultural production and fresh water tends to be increasingly demanded for non-agricultural uses, reducing its availability for agricultural production. The new solutions should address this and other problems of present or potential environmental degradation, combining the knowledge in those areas with gene technologies, management of natural resources and local knowledge. Approaches should be sensitive to local environmental and socio-economic realities with special attention paid to the needs of women farmers.
- Multidisciplinary science can play an important role in addressing different parts of the research continuum. Different fields of scientific enquiry, for example geography, hydrology, anthropology, psychology, communications and ecology, are often not considered to be part of the traditional agricultural research portfolio, but they do impact the lives of people in agrarian societies.
- Developing countries need a larger framework of trained scientific personnel in all scientific areas. They also need to provide these professionals with good working conditions that allow them to realize their potential for developing adequate scientific solutions to their own unique problems. Capacity-building, directed by the development of a research agenda that addresses local and regional priorities, is urgently required.
- Science does not thrive in isolation. Because of the private sector-driven nature of new scientific developments in developed countries, there is an ever-widening scientific gap between countries of the North and South. North-

South partnerships, as well as South-South coordination, are a way of helping to bridge the gap and create a critical mass in scientific research that would be difficult to achieve by any one country acting alone.

- Science generates a large amount of information that needs to be processed and adapted to be useful to society. Information needs to be translated in simple terms in order to be understood. Information technology is increasingly available but is not user-friendly. Information and information technology must be tailored to suit local needs. User-friendly interfaces for properly delivering available information are necessary for all sectors of society.
- The increased participation of the private sector in research has been brought about largely by guarantees of intellectual property rights (IPR) and protection. However, there is a fear that research (both products and processes) will be focused towards the needs of only those who are willing to pay, to the detriment of small farmers. Therefore, there is a need for more public sector investments to address these research areas that are of direct concern to poor farmers and developing countries.
- Scientific endeavour, particularly that which involves genetic engineering and development of transgenic organisms, is being examined in terms of its ethical and moral as well as market implications. Societal responses to such issues reflect the cultural differences among communities and countries and debate on these issues is sometimes marred by partial scientific knowledge. Public awareness and communication, grounded in scientific evidence, is needed in order to promote a more informed debate.

The Chairman concluded the meeting by offering the following thoughts:

- For the last four decades, the world's population has benefited immensely from science-based growth in agricultural productivity. Increased food production has enabled populous countries in Asia to avert catastrophic famine. Lower food prices have enabled greater access to food by the poor, both in rural and urban areas. For the urban poor, lower prices have helped to reduce poverty since food purchases account for a major portion of their income.
- Increased use of external inputs (fertilizers and crop protection chemicals) that enabled farmers to exploit the higher yield potential of modern varieties has been cited as one of the drawbacks of the 'Green Revolution' technologies. But such criticism has been tempered by the fact that 'Green Revolution' technologies resulted in saving millions of hectares of land from being brought under plough. This land was 'saved' in the best sense of the term and the savings have been substantial: to produce the same amount of food that was generated by the improved technologies, an additional 300 million hectares of land would have been put into cultivation.
- Food security has many dimensions. It means not only a greater food supply but also improved access to it. It means that food security is not only about increasing productivity by making sure that production practices are sustainable. Food security can be enhanced by applying good technology and implementing appropriate policies. Food security is both a rural and urban issue, and enhanced food security has occurred at all levels: household, national, regional and global. And empowerment of women will be a crucial element.
- Providing food for the additional billions of people in the next century while protecting the environment will need science more than ever before. The revolution in biological sciences, especially the advances in molecular biology, bioinformatics and genomics, are increasingly being deployed as powerful tools for improving agriculture and protecting the environment. But their promise is being realized in the laboratories and production fields of industrialized countries only and this has yet to happen in developing countries where the need for increasing productivity is vital. The new technologies have generated safety, ethical, environmental and social concerns and all these concerns must be addressed if the new technologies are to be safely and equitably deployed in the service of developing country agriculture.
- The challenge is to bring about productivity increases through intensification of agriculture at the smallholder level in the developing countries. Sustainable agriculture will be the key and would require a synergistic combination of genetic technologies and sound natural resource management. Meeting these challenges will also need the commitment of all stakeholders and it is only then that we will be able to realize the promise of all that science can do to benefit the poor and the environment.

Introduction

HE Vigdis Finnbogadottir
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Progress in science has always induced man continually to push back the limits of knowledge, to enable him to become, as Descartes put it so aptly, 'the master and possessor of nature'. Nevertheless, the heightened awareness of the human and social implications of scientific research, the presentation and utilization of its findings, as well as its technological applications, have given rise to a new factor: scientific progress and communication strategies consider ethics as an integral part of their development.

Today, as we all realize, there is a certain degree of disillusionment about science, especially in the developed countries. Science and scientific progress are indeed raising urgent questions, for example in the field of genetics and notably of human cloning, whose ethical implications will be discussed in this meeting by Mrs Somerville. It has been seen over the past 15 years that scientists have grown aware of their responsibilities. They have, for example, displayed genuine concern about nuclear weapons. As for genetic engineering, it was scientists who decided on the Azilomar moratorium. It is specialists, too, in climatology and hydrology who have been concerned about the problem of global warming. There can no longer be any doubt that the scientific community is aware of its heavy responsibilities.

Social upheaval and the need to monitor the extraordinary advances of science and technologies in a harmonious way are causing ethical issues to loom larger and larger. Much of this questioning touches on areas relating to UNESCO's fields of competence. Who should determine the priorities and choices of science and technologies and on the basis of which social goals? How can we define democratically the risks which can be considered as 'acceptable'? What is the level of responsibility and solidarity which can be expected from individuals and groups in relation to both present and future generations?

These choices necessitate that public opinion has access to clear and objective information. Hence, this raises not only the question of the existence of a general duty of scientists and researchers to inform society at large, but also the question of transparency of scientific research.

With advances in science and increasing consciousness of potential risks, the rights and duties of scientists and researchers have a renewed relevance. Because of the importance of the implications of the utilization of scientific knowledge, science constitutes henceforth a power, a topic to be developed by Mr Ida, just like economic power or political power with which science has interdependent relations. On the one hand, science implies political decisions, as we all know. On the other hand, science needs significant financial investments and is governed by market forces, raising the question of private or public financial sources. The nature of funding supplying science has some important consequences on the issues of access to scientific data, the privatization of scientific knowledge and results, patents on the living and techniques used. Concurrently, science also generates enormous gains and profits. So it may be more and more difficult, if not impossible, to dissociate scientific knowledge from economic power.

The financial aspect of science has repercussions on the independence of scientists and researchers: how can this independence be guaranteed while scientists and researchers have to account for their activities to the bodies which finance them? Should a scientist also be a businessman? Is there not a risk of divergent interests in cases of multi-jobbing – a risk that economic pressures and policy risk will prevail over considerations of public health?

An increase in scientific power could lead to the decrease, to a certain extent, of the principle of precaution. This principle will be developed by Mrs Belicza. What are the limits of this principle? Does precaution mean stopping any research until all the effects it might generate are known in order to attain zero risk? Or does it mean that precaution should be based on the notion of acceptable risk?

The answers to these questions go beyond the narrow confines of professional practice and national borders. In a multipolar world of an unprecedented splintering of perceptions, it is more than ever necessary to strive for the emergence of values which would make our common existence technologically, ecologically and socially viable.

Such ethical reflection calls for a free and open exchange of experience and ideas among decision-makers, specialists and representatives of civil society, in all its diversity, in order to identify the issues, set points of reference and advocate a range of forward-looking alternatives.

The development of science must henceforth be examined within a new framework. At the end of the 20th century, the 'battlefield' has become primarily one of economic warfare. And the fact is that economies are increasingly being dominated by scientific knowledge, technologies and information which has now become the true centre of power. What has to be done is to develop new forms of knowledge and share them. Sharing knowledge goes together with sharing responsibilities. Science needs to be perceived as a liberating force.

But we cannot overlook the gap between the state of science in developed countries and in developing countries, which Mr Cantú and Mr Wandiga will speak about. Some developing countries are facing crucial choices. The management of resources by the state, which is seeking to improve the livelihood of its citizens, is an issue that often arises in an urgent manner.

Indeed, those are among the major concerns raised by science, ethics and responsibility in a globalized world, where the gaps are widening between info-rich and info-poor, gene-rich and gene-poor, where individualism stands versus common good, where human power on nature and on human bodies is at stake.

It can be seen today there is a twofold failure of understanding between laboratory science and populations on the one hand and laboratory science and decision-makers on the other. This failure often stems from a lack of knowledge and is based on mistrust and fear.

The public expects more and more that major engineering works, in particular those involving technological hazards, be preceded by comprehensive, stringent and independent technology assessment studies. These studies should take into account those unavoidable risks which are inherent to technologies. Indeed, technological risks must be reduced to a minimum, but they cannot be altogether eliminated: zero degree of risk does not exist. These studies should also address the question of hazard management. The results of such studies should be made public in an appropriate form, i.e. in an accessible language.

The three 'Ts' in this exercise are: Transparency, Truth and Trust. Of course, transparency is time-consuming, but it is an essential ingredient of trust. This is also the case for truth. Misinformation or half-truths fuel rumours, induce fears and discredit those responsible for public information.

Of course, a number of international guidelines and directives adopted by intergovernmental bodies which address these issues exist: take as an example experimentation on human subjects or clinical trials, not to mention national legislation passed by parliaments on these questions.

Associations, consumer groups and other non-governmental organizations have a key role to play in this area provided they are involved from the inception of any project.

A public debate, with the participation of all actors concerned, including communicators, can only enhance a democratic process that is very much needed in this area. The road lies before us and, if there is still a long way to go, maybe we know the indispensable provisions needed while undertaking the voyage. One such provision is certainly a strategy of communication, in order to ascertain comprehensive information and a sense of solidarity.

Appropriate communication can only be based on the accuracy of information, as well as on a concerted effort of education. The duty of responsible communication must be met by the right to accurate information, including that concerning uncertainties when these exist. Similarly, the better educated a public is, the less likely it is to yield to misinformation. Nevertheless, it would be an illusion to think that irrationality can be completely eliminated; it can only be reduced.

In a world of ever-multiplying options, we expect no less from younger generations than a readiness to make the right choices for themselves and for future generations. But do we prepare them adequately to assume this role, not only intellectually but also morally? Do we provide them with the tools to critically assess priorities, make judgements about the values involved and ground their decisions? Do we give them the feeling that we all belong to one planet that craves international solidarity?

The most topical example of the need for ethical safeguards in regard to scientific progress lies in the field of genetics. This example reminds us of the ambiguity of science, which is one of the most powerful ingredients of societies. Today we can no longer close our eyes to the ethical issues implicit in science. It is no longer possible to envisage an ethical neutrality of knowledge that would be independent of its subsequent applications. Thus, the General Conference of UNESCO, on 11 November 1997, adopted the *Universal Declaration on the Human Genome and Human Rights*. This *Universal Declaration* provides a consistent and comprehensive set of ethical principles which should guide both research and applications of research findings in biology and medicine.

As a conclusion to this overview of my main concerns, as President of the World Commission on the Ethics of Scientific Knowledge and Technology (COMEST) and as a citizen, allow me to emphasize that this situation in the world, as it is developing, places new responsibilities upon the scientist, the engineer, the decision-makers both private and public (in particular in the industrial sector) and the citizen. These responsibilities can only be assumed through discussion and the construction of common values.

The three guiding principles could be outlined as:

- the principle of precaution weighed against the level of acceptability of a risk;
- the principle of participation of all actors involved in a project;
- the principle of monitoring signals that should alert us.

The first session of COMEST, which was held in Oslo in April 1999, has clearly demonstrated the extent of the power that man now has over nature due to development of science and technology. Several conclusions can already be drawn from the deliberations of this first session, among which are the following.

- The need is being felt to create a parliamentary office of scientific and technological assessment in the countries which do not yet have one. Such an office, which aims at providing guidance to the legislator in the decisions he is led to take, also constitutes a forum for exchange and dialogue between the scientific community and political circles around interest and needs to be expressed to the common man who has the right to know what is going on.
- The possibility for COMEST to set up an ‘ethical audit’ on the activities undertaken within its fields of competence. This ethical audit should make explicit ethical principles and decision rules underlying science programmes or societal policies. In accordance with its mandate, COMEST could specify ‘good practices’ in the fields it will have examined and it will, of course, be for the Commission to highlight the principles and define the criteria to be applied in these ethical audits.

The increasing gap between North and South: a globalization paradox

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North and South have been commonly identified with the developed and the developing countries, despite the fact that some appear in the wrong hemisphere. The outstanding achievements of science and technology are pulling down many geographical obstacles at the end of the 20th century, allowing globalization, which, so far, is being managed by economists and politicians.

Nevertheless, globalization is becoming more and more difficult to achieve given the differences between rich and poor which, in the last third of the 20th century, have increased at least twofold with all the consequential disparities in access to health and education. In biomedical sciences the gap between developed and developing countries is constantly growing. For example, more than 40 000 people will receive doctoral degrees this year in the USA, whereas fewer than 4 000 will do so in Latin America (about 20% in biomedical sciences). Such an abysmal difference has been similar for every year of the last half of the 20th century and is reflected in many other parameters of scientific development.

Genocides, apparent or disguised, are occurring in many countries under irrational rationalizations. There is an underlying process of dehumanization due to the overwhelming temptation of money that has led to an outrageous excess in consumption submissively adopted by most cultures on Earth. Globalization means integration, inclusion, incorporation. We must learn to love globalization. Many sacrifices are necessary to abandon patriotic traditions, customs and beliefs. In the end we will all be earthlings.

Globalization at the scientific level requires the effort of the scientific communities of both developed and developing countries. The exchange of scientists sounds a logical initiative. A Northern country could associate itself with Southern countries with which it has an affinity to do research of common interest. For instance, European institutions could build up biomedical laboratories to study AIDS and tropical diseases in Africa. Of course, those who have more must share more.

Is human cloning inherently wrong?

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Human cloning confronts us, in a profound and dramatic way, with the ethical dilemmas and choices faced as a result of recent, extraordinary scientific advances. The critical ethical question it raises is: What, if anything, will we choose not to do with the new science because we believe that to do it would be inherently wrong?

An 'inherent wrongness' approach is currently very unfashionable – almost politically incorrect. One reason is that, no matter how much good could result from an inherently wrong intervention, we must not do it. We find it very hard to deny ourselves benefits as individuals, especially for the sake of a larger good. Another reason is that this approach is often associated with religion which may not be used in a secular society – at least directly – as a basis for public policy.

Most contemporary, societal-level 'ethics talk' is based on situational ethics, a view that nothing is inherently wrong and that, rather, it all depends on the circumstances. This approach allows 'doing good' as a justification for unavoidable harm. It also allows us to avoid the great difficulty of establishing consensus on inherent wrongness in the pluralistic, democratic, multicultural, secular societies in which much of the avant-garde scientific research, such as genetic manipulation of human embryos, is being undertaken. Such consensus might even be impossible when we no longer have a commonly agreed upon external moral authority – whether God, religion or an absolute monarch – to whom to appeal as the final arbiter of right and wrong. In short, can we believe in a moral absolute without needing to believe in a supernatural being? More precisely, can we believe that human cloning is inherently wrong without believing in God?

A secular test of inherent wrongness might be formulated on the basis of two values: first, we must always act to ensure respect for life, in particular, human life. And, second, we must always act to protect and promote the human spirit. The development or use of any given science or technology that would harm either of these two values is inherently wrong.

Before seeing how human cloning measures up to this test, the language in which it is formulated merits comment. We lack a secular vocabulary to describe the essential, invisible, intangible and unmeasurable reality which we all need to live fully human lives. In this lacuna, the terms that we use to describe this metaphysical reality often have a religious connotation or are associated with certain ideologies. This can cause some people who reject religion, or do not share the particular beliefs or ideologies with which the terms are associated, to reject the values described in this way. But we can, for example, be atheists and yet accept the concept of the human spirit and the need for the (secular) sacred – that which we must respect at all costs.

Good facts are essential for good ethics and the facts change rapidly in the new science. Recent research advances mean that human cloning may now be undertaken with one of two aims. Scientists can seek to make a genetically 'identical' child of the person cloned – so-called 'reproductive cloning'. Or they can create multiple, genetically identical embryos to be used for research or to produce human tissues or organs for transplantation – so-called 'therapeutic cloning'. More people oppose reproductive cloning than therapeutic cloning, but we need to consider whether either or both are inherently wrong.

Therapeutic cloning involves research on human embryos and their destructive use. Many people regard such research as profoundly unethical and even those who do not have placed major restrictions on it. For instance, only so-called 'spare' embryos left over from *in vitro* fertilization (IVF) procedures may be used. Those who allow human embryo research do not regard the embryo as an individual and, therefore, see no breach of the value of respect for individual human life in using it in this way. But we also have an obligation that arguably no previous generation of humans has had, because they could not, as we can, interfere with the essence of human life. We need to maintain respect for human life, itself, in general. Would creating unlimited numbers of human embryos from spare embryos, using embryos simply as 'living human tissue generators', or creating human embryo manufacturing plants destroy this respect? Moreover, we hold both human life and respect for this on trust for future generations. What are our obligations from this perspective in deciding whether or not to undertake therapeutic cloning?

For instance, therapeutic cloning will help to open up technologies that can be used to alter the human germ cell line, the units of heredity that are passed down from generation to generation. Should we prohibit any interference with this? If so, apart from other reasons, should we prohibit therapeutic cloning in order to make this prohibition less likely to be breached? But would it be ethically acceptable to modify a single gene in the germ cell line when this would avoid a child being born with a lethal disease? If so, would it be ethically acceptable for parents to choose to have their embryos genetically altered for enhanced intelligence or other desired characteristics? Are we willing to accept the creation of two distinct groups of humans, whom Professor Lee Silver of Princeton University has described as the 'gene-rich' and the 'gene-poor'? He predicts that the gene-rich will want to reproduce only with other gene-rich humans.

If we are 'genes-R-Us' or 'gene machine' adherents – that is, we essentially see humans as highly complex, functioning DNA, including with respect to our most human moral characteristics, such as empathy, caring and altruism – we might not have a problem with therapeutic cloning and its sequelae. This is especially likely if we validate our interventions with a 'doing great good' justification. If, however, we are 'human spirit' adherents – and especially if we regard having a sense of wonder about life and the fact that we exist at all as being of the utmost importance and essential to our human well-being – we could not accept such a use of human embryos.

Sometimes we use a change of language to try to overcome ethical problems. For instance, we have spoken of 'pre-embryos' – embryos in the first 14 days after fertilization – to try to avoid the ethical dilemmas of carrying out research on human embryos while still undertaking this. Now we are using the term 'human embryonic stem cells' to describe the cells taken from an embryo to be used in therapeutic cloning. But these cells are totipotential – each of them is capable of forming another identical embryo. What ought to be the ethical impact of this fact in terms of what we should not do to human embryos, in particular, because we want to maintain respect for human life, itself, both for ourselves and for future generations?

To turn now to human reproductive cloning. The secular-based arguments that this is inherently wrong include that: each of us has a right to come into existence through human reproduction, not replication, and a right not to be designed by another human, not to be manufactured. We have a right to our own unique genetic identity (naturally occurring, genetically identical twins aside), to our own individual ticket in the great genetic lottery of the passing on of life. Respect for human life in general, and that of each individual person, and for intrinsic human dignity would be breached by cloning. The same is true regarding respect for genetic diversity and the integrity of the human gene pool. This is the common heritage of humankind and must, because we now have this unprecedented power to interfere with it, be held on trust for future generations.

Another line of argument against human reproductive cloning comes from focusing on the child and putting her or him at the centre of the 'infertility business' and not, as has so far been the case, the infertile person or couple. Ethical concerns in relation to the child include: physical and psychological risks to him or her – imagine a teenager clone trying to differentiate from her parent or a clone's 'parent' trying to correct the mistakes he believes his parents made with him; the possibility of new forms of genetic discrimination; risks to important values governing human bonding and the family; and the impact on important values of the commercialization of human reproduction, in particular, human cloning. This technology goes to the very essence of the nature of us, the meaning of human life and the fabric of our most intimate relationships.

Nature never contemplated needing safeguards against science such as human cloning. It was thought that there was a natural barrier, that genetic material in a somatic cell was irreversibly modified in such a way that you could not obtain a clone from it. Dr Ian Wilmut showed, in creating Dolly, that this was not true. What does this power require of us in terms of our human responsibility to hold nature 'in trust', in particular for future generations, and especially that part of nature that constitutes the fundamental nature of us? If we were to undertake human cloning, what kind of creatures might we become? At the least, we as the public need time to think about this. It has taken millions of years since life first appeared for us to evolve to our present state, but scientists can now change us in seconds. Ethics, however, takes time and we must do science 'in ethics time', not the converse.

Science, ethics and responsibility in a globalized economy

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Science

Science is practised by individuals who are keen to discover secrets of nature. First and foremost, there must be an interest, a mystique and a desire to learn. The interest is aroused by an observation followed by a perusal of facts. Without an organization of known facts, the interest soon fades away. In short, an individual observes a mystery that arouses the interest. The person organizes the known facts about the observation. This leads to discovery of more facts, a process called research.

In order for a practitioner of science to fulfil a career, some necessary support must be there. We do not really know how much we have discovered and what remains. New technologies, methods and discoveries require sophisticated equipment and methods. Such sophistication is expensive. It is therefore necessary that the present-day scientist be trained. Educational institutions such as universities, research institutes or industrial research complexes are essential for promotion of science. These educational institutions become what I call, for lack of a better term, ‘incubators of knowledge’.

The successful incubator of knowledge must be well supported with a clear mission for its operations. Transformation of possessed knowledge into a technology is a propellant and major driving force for the success of an incubator of knowledge. Often, transformation of knowledge into technology requires close links with ‘incubators of technology’. These are the polytechnics, the institutes of technology and more often industry itself. Gestation of technology occurs at these institutions. Experimentation to find out what works, what sells, how it is perceived by the market takes place in these institutions. They therefore build a bridge between the public and the individual, the knowledge institutions and the technology institutions.

Of course it is possible that some knowledge institutions may process their knowledge directly into a market product by utilizing some of their internal organs. Such an occurrence does not negate the process described above, but raises the ethical question: does this market approach prompt the release of results/products before time/before full evaluation?

The problem with science in developing countries is that we have evolved science policies that emphasize training of the individual only. Once trained, the individual who has knowledge is ill-equipped to transform his knowledge into technology. Polytechnics and institutes of technology are given low ranking in social status and individuals at these institutions do not relate to those in knowledge incubator institutions. Technicians are trained to service old industries which have no new knowledge. Changes in technology force their retraining. The process leads to the acceptance of the dictum that states that it is hard to foster scientific policies in largely agrarian economies. Therefore, there is a strong need to change the science and technology training policy in developing countries to forge close collaboration and cooperation between these institutions.

The economic policy of a country greatly influences achievements in science. Evidence available today indicates that a country may have an oversupply of graduate scientists and technologists who will not have an impact on the economy if the country’s economic policy is wrong. On the other hand, advances in science and technology influence and change the economic policy. Advances in science and technology dictate changes in economic laws. The establishment of new social structures and institutions to protect human health and the environment may be required. Developing countries need to take advantage of growth in knowledge to improve growth in industry. For a start, we may use new technology to improve agricultural methods.

Therefore, training alone without a clear economic policy will not bring societal change. It is through economic policy that the individual, the incubators of knowledge and the incubators of technology will be motivated. Reliance on support from taxes alone, though essential, is not a sufficient drive for success in science.

In the above discussion, I have tried to show the linkages between science and society. I have shown that national policies form the bedrock of science promotion. A second level of science promotion relates to our quest to understand phenomena that affect a region or impact globally. A few examples of such phenomena include our understanding of global ocean circulation and climate change, the global warming effect as a result of fossil fuel and biomass burning, loss of biodiversity and the threat of desertification, to name but a few.

Collaboration between scientists from various disciplines supported mainly by developed wealthy nations and

United Nations organizations has advanced human understanding of natural phenomena whose effects are felt the world over. For example, when it strikes, the El Niño-Southern Oscillation effect is felt most by poor countries. Therefore, by combining technology, science and human understanding, we not only further our knowledge but also our capacity to intervene in the interest of humanity. Today, we know more about these phenomena than 20 years ago.

Translation of the results of such studies to local situations becomes the responsibility of national/regional scientists. Therefore, it is a must to build the capacity of nationals from developing countries through their participation. It is also my submission that, since developing countries benefit from such studies, they should also contribute towards the support of such science, no matter how little. Free gifts are rarely appreciated. By contributing, the developing countries will have a voice in the control of such programmes.

Ethics

Ethics of science relates to the rules and regulations of the conduct of science. The ethics of science prohibits scientists from falsifying their results. It dictates that plagiarism shall not be accepted. It regulates how test animals are to be treated and prohibits experimentation with humans. It can be said that the practitioners of science in both the developed and developing world, by and large, follow the ethics of science. There exist disciplinary procedures for punishing violators. The dark side of ethics is what I may call our interpretation of ethics for science.

By ethics for science I mean the rules and regulations a society establishes for the application of science. The cracking of the atom by scientists is a major scientific achievement. The construction of the atomic bomb and its use in war is a political decision that relies on the ethics for science established by a society. A second recent example relates to the cloning of Dolly the sheep by scientists through genetic engineering. The cloning of humans through scientific knowledge, though feasible, is an ethical question decided by a society or societies.

However, the lines between right and wrong are very difficult to determine if human cloning results in attempts of science-fiction-type genetic engineering to create the perfect human being. One might argue that this is wrong and gets in the way of nature. However, when the same process leads to tissue/cell regeneration (e.g. in the case where such tissue/cells have been destroyed by cancer) and thereby reduces human suffering, can one be as quick to judge it as wrong? Furthermore, if the process is allowed to exist for the latter reason, what is to prevent it from being used for the former? Such questions become important in an age where globalization is increasing. Under such conditions, what was previously one society's decision now becomes a global decision with global impacts.

Take the example of abortion. The technology is now affordable and replicable enough to make it globally available. However, whose decision should it be to carry through an abortion? Countries, societies that have what are considered conservative stands on the issue (i.e. abortion is wrong and cannot be tolerated) now find themselves invaded by human rights groups that say it's a woman's decision and that enable women to have access to the procedure. Putting aside the debate over choice for a second, the interesting dilemma is that a scientific technique deemed acceptable by one society is being imposed on a society that has decided it is not acceptable. Under such conditions, who then decides which viewpoint must prevail?

As you can see, it is in the ethics for science that we have major problems and challenges. Furthermore, advances in science have left developing countries behind. Participation of developing countries in discussions on ethical issues has not seen strong contributions from these countries. The question that begs an answer is, who should decide these issues on behalf of developing countries?

Responsibility

The noble aim of science since time immemorial is to benefit people. A new requirement of science is the benefit to the environment. In this way, scientists have been the most generous people in sharing their knowledge freely and without hindrance. Most of the well-known scientists died poor. The glory through recognition as the discoverer of a phenomenon was all that was needed. This is becoming less of an aim since the invention of patent laws and market forces. If the pioneer microbe hunters had kept secret their scientific discoveries, one wonders whether we could have made advances in the fight against diseases like smallpox, tuberculosis, against bacteria?

What I am alluding to is this. There are advances that have been made in finding a cure for AIDS, through a combination of drugs. These advances have not reached the AIDS sufferers in developing countries, due to patenting and economic forces. However, as I mentioned before, there is an inexorable link between scientific policies and economic processes. The dilemma arises when economic forces that have a primary aim of profit prevail over scientific forces with the primary aim of human benefit. The question is, how responsible are we when we see thousands die even though their lives could be prolonged. Must the 'ability to pay' completely cancel our senses for the 'ability to benefit'? Where is our sense of responsibility to other people?

Such are questions we face in our modern world of science. Many of these questions have been prevalent since the beginning of science. However, in a world where societies and cultures are increasingly linked, the impact and significance of the answers is much larger than ever before.

I hope that, with these brief thoughts, we can collaboratively begin to address the questions and answers that affect us all both as scientists and as global citizens.

Science, ethics, responsibility: the principle of precaution

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It was almost 500 years ago that European philosophers, starting with Thomas More's *Utopia* (1516), announced the possibility of ideal societies based on the expansion of knowledge, particularly advancements in natural science and technology. A hundred years later, Francis Bacon, in his *Sylva Sylvarum* (1627), provided a list of 'General natural achievements especially in respect to their use by man', which includes: 'The prolonging of life; The restitution of youth in some degree; The retardation of Age; The curing diseases counted incurable; The mitigation of pain; More easier and less loathsome purging; The increasing ability to suffer torture or pain; The altering of complexions and fatness and leanness; The altering of statures; The altering of features; The increasing and exalting of intellectual parts; Version of bodies into another bodies; Making new species; Transplanting of one species into another; Exhilaration of the spirits and putting them in good disposition; Force of the Imagination either upon another body or upon the body itself; Acceleration of time in maturation and clarifications; Acceleration of putrefaction; Acceleration of Decoction; Acceleration of Germination; Making rich composts for the earth; Impressions of the air and raising of tempests; Great alteration of induration, emolliention etc.; Turning crude and watery substances into oily and unctuous substances; Drawing new foods out of substances not now in use; Making new threads for apparel and new stuffs such as are paper, glass, etc; Natural divinations; Deceptions of senses; Instruments of destruction as of war and poison.'

At the time it was written, this list probably looked a lot like what we would call today science fiction – predictions, however, not requiring the need to raise – even hypothetically – the question of the principle of precaution for a scientist from the perspective of a scientist, scientific community, society or its citizens. Today, the list looks like a public announcement for present and future research strategy. It is no longer utopian, however. It is becoming reality, with predictable and unpredictable consequences. Scientists and researchers have already started the adventure of reshaping life by using molecular biology, genetic engineering in agriculture, genetically manipulated animals, cloning, transgenic organisms, xenotransplantation, to name a few.

Scientific research is no longer the individual interest of dedicated explorers and discoverers. It has become a powerful industry, producing new knowledge and new technologies. Governed by or being used for the market economy, based upon the principle of profit and political power, and joined with the struggle for social and professional recognition, science can no longer be considered a priori as globally beneficent, progressive and harmless, as per se ethical and moral.

It is rather symptomatic that these aspects have been primarily recognized in the field of medicine and biomedical research, although medicine and biomedical research are just the tip of the iceberg, indicating very complex substructure and interactions originating from basic scientific postulates and contemporary scientific knowledge and technology.

Questions on the exercise of professional power and its limits were first recognized and raised internationally during the Nuremberg medical trials. On the 50th anniversary of the Nuremberg Code, elaborated in 1947 in the course of the trials against Nazi doctors, one of the panellists of the First World Conference on Ethical Codes in Medicine and Biotechnology in Freiburg, Germany, in 1997 delivered a lecture entitled 'How could it happen?' It is a symbolic question not only in relation to the past when science and scientists inspired and participated in the political and social goals of the Third Reich in Nazi Germany – but a question present and future generations might one day ask about our present responsibility.

We do not want to forget that medicine is a perfect and ultimate medium for testing, verification, evaluation and practical implementation of scientific ideas and technologies, their relations and interactions. It provides very complex biological, social, economic and political enterprise for scientific observations and experiments in time of prosperity or disasters, in time of peace or war, either in short- or long-term studies.

However, in comparison with the abundance of instruments of medical professional conduct, conventions, declarations and guidelines regulating medicine, health care and biomedical research on the universal, national, local and institutional levels, there is a clear gap in the development of such instruments for scientists, researchers and scientific research in general or in a particular branch of science.

Declarations, conventions and professional conduct are just the first step. They do not solve the problems. Their main role is to identify the problems and set up the strategy and principles based upon the goals in a particular time and place.

So the principle of precaution, the precautionary principle or the precautionary approach, evolved as a response to the environmental and human health impacts caused by rapid industrial growth following the Second World War. And with the extremely apparent weakness of early pollution control legislation, it has gained international acceptance as a guiding principle for environmental decision-making. It was introduced in 1984 at the First International Conference on Protection of the North Sea. Following this conference, the principle of precaution was integrated into numerous international conventions and agreements. One of them is the *Rio Declaration on Environment and Development* (1992), which, in Principle 15, states signed that:

‘In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.’

From the very beginning, the precautionary approaches are goal-oriented, starting from the presumption that the question of what society should do in the face of uncertainty regarding cause-and-effect relationships is necessarily a question of public policy, not science.

The Wingspread Statement on the Precautionary Principle from 1998 postulates too:

‘… When an activity raises threats of harm to human health or the environment, precautionary measures should be taken; even if some cause-and-effect relationships are not fully established scientifically, it is necessary to implement the Precautionary Principle.’

In this statement, science and scientists are not excluded but, on the contrary, they are explicitly included:

‘Corporations, government entities, organizations, communities, scientists and other individuals must adopt a precautionary approach to all human endeavors. The process of applying the precautionary principle must be open, informed and democratic.’

The presently increasing consciousness of the possible damaging impacts of science, technology and scientific investigations on a global plane demands the rethinking of the declarative principle of the freedom of research and requires raising the question of priorities and responsibility of the individual scientists involved in scientific research. Ethical foundations of scientific practices and methods are becoming *conditio sine qua non*. With respect for the principle of precaution, such orientation should accomplish the question of values, ideals, duty, morals, honesty, virtues and standards, the question of prevention, handling and investigation of misconduct and fraud, plagiarism and dishonesty in scientific research, the question of goals, methods, risks, subjects and objects of research, as well as the question of decision-making based upon the individually informed choices of the scientist, researchers and citizens.

The precautionary approach urgently demands needed guidelines and norms related to good scientific practice and its violations, as well as an open dialogue with society not only in relation to decision-makers and politicians, but also on the level of the general public and individual citizens. The time has come when scientists, researchers and technologists should accept the same basic ethical principles as their colleagues who are involved in medicine: respect for autonomy and dignity; the principle of beneficence; the principle of non-maleficence; the principle of justice; the principle of informed consent and informed choice.

It is very important to develop the decision-making process based on the principles of responsibility, partnership and the precautionary approach, not only when there are threats of serious or irreversible damage and a lack of scientific certainty. In a free and democratic society, the same principles should be implemented whenever the application of scientific knowledge and technology is to be decided.

Scientific power, economic power and political power

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Science and power

Science is a source of power. I will discuss not the power of science itself, but the conditions for science to be a true source of power. Two considerations are necessary: preoccupations of scientists and social constraints. One is 'ethics for science', and the other is 'ethics of scientists'.

'Power' has traditionally been defined as military or political power. However, the military factor of power has reduced its value because of the prohibition of the use of force enshrined in the United Nations Charter. 'Power' has a more peaceable meaning now. Hence the increasing importance of economic power. To take Japan as an example, the secret of Japan's economic power is principally its science and technology. Japanese people have demonstrated their keen ability to adapt and apply the basic scientific and technological knowledge and skills brought into Japan from China and Korea since the 5th century, so that Japan's own science and technology has been fermented. Science has thus been the power basis of a country.

In our time, and not only in Japan, science has become a kind of ultimate source of power at least in the following three aspects:

- first, the development of our ability to communicate has been tremendous, making the Earth really 'one'; the ability to produce and transmit information is a tool for measuring power;
- second, science and technology are the basis of people's industrial capability and thus determine the economic power of a given country;
- third, a new field of science, called 'life science', may control the whole of human life in the very near future.

These aspects are key features of contemporary science. Such features, however, give rise to various social, ethical and cultural problems, and people are now fully conscious of the benefits and the dangers of the progress of science.

Needless to say, the basis of science and scientific progress is the freedom of research, which is a human right. This is particularly so in the most advanced fields of science, like human genome research, as stipulated in Article 12 of UNESCO's *Universal Declaration on the Human Genome and Human Rights* (1997). But the freedom of research supposes some 'practical' factors to fully enjoy such freedom and some constraints vis-à-vis society.

Preoccupation of scientists: ethics for science

Scientists have three preoccupations concerning full enjoyment of research freedom.

- Independence of scientists. It is absolutely crucial for scientists to have a guaranteed independent status. Research should be conducted according to the conscience of each scientist and no type of outside pressure should be brought to bear on a scientist. Independence is the basic reason for scientists' self-regulation.
- Material and financial environment. A sufficient material and financial environment enables scientists to carry out research and facilitates their work. Freedom of research will mean nothing if scientists lack sufficient materials and funds.
- Societal acknowledgement of research. Research itself being self-sufficient, societal acknowledgement gives researchers a valuable incentive to do further research. The patent compensates the researcher's efforts. Publication is a measuring tool of the value of research.

With regard to each of these factors, scientists often experience some psychological, material, financial or even social difficulties. Scientists should be discharged of all these preoccupations. In particular, scientists are always anxious to get financial and material support. This is all the more the case in basic scientific research, which has apparently few practical benefits. To say that science is a source of power misleads people to believe that science always gives practical, concrete and visible benefits.

Constraints: science should follow some constraints in a given society

Science has its own existence in a given society. This relates to the ethics of scientists. We may take genome research as an example to show what are the issues involved and what are the constraints.

With the tremendous amount and variety of data and information contained in the genome, this field of science, called 'genome science', has a wide impact on human values and human life: many questions are to be reconsidered, for example the concepts of life and death, normality and anomaly, just and unjust, equality and discrimination and so on. Thus, numerous social, legal, ethical and cultural issues are involved.

Human genome research

Through the analysis of structures and functions of DNA in human beings, human genome research will lead us to total comprehension of human biological functions and thus may change some core conceptions concerning the human being, namely, the life, identity and diversity of human beings. What is at stake is thus human dignity. To what extent then and how is human genome research permitted? Obviously, bioethics plays a central role here.

From this standpoint, we should refer to a very important instrument, the *Universal Declaration on the Human Genome and Human Rights* adopted by the General Conference of UNESCO in November 1997 and endorsed by the General Assembly of the United Nations in December 1998.

In this *Declaration*, research freedom comes face to face with the human rights of the patients or persons concerned. For scientists, it is necessary to respect the rights of the person concerned, namely the principle of informed consent, the confidentiality of genetic data, the protection of vulnerable persons and so forth. Also, since the genetic characteristics and data represent the identity of each human being, any discrimination originating from genetic differences is strictly prohibited[1].

On the other hand, we should not overlook the economic implications of human genome research. The development of human genome research makes the most advanced medical care possible and creates a new scientific and industrial branch, 'pharmaco-genomics'. Such developments surely contribute to maintaining and improving people's health. But at the same time, better medical care may increase the numbers of old-aged and strain the social security system. Thus we face a triangle of human rights, bioethics and the logic of the market economy.

Genome research other than that on the human genome

Genome research other than that on the human genome has profound economic and social implications.

First, the impact of genome research on industrial applications is wide and diverse. The results of research are applied mostly in the agriculture and livestock industries. The creation of new or improved species by genetic manipulation may bring about important changes in the industrial structure of a country. The economic impact of new, highly productive species affects not only the production and consumption systems of a country but also international trade relations.

Also important is the influence of genetically manipulated plants or animals on the environment. Conflicts between such plants or animals and existing species may cause the weeding-out of wild species and accordingly interfere with biodiversity, so as to bring about eventually irreparable damage and changes to the ecosystem. This is one of the main subjects of the Convention on Biodiversity.

The third point is the possibility of unknown dangers and risks brought about by any genetic manipulation. A researcher certainly seeks the utility of new or improved species that were non-existent before, but he/she should recognize also the unknown risks or dangers, even if theoretically there should be no difference and no harm. This is a field where the precautionary principle should play a key role.

The logic of the market economy holds a particularly important position in biotechnology today. Medical and pharmaceutical industries have come to offer their assistance to researchers as a kind of 'investment', because these industries intend to obtain the fruits derived from the research in which they invested: in particular, they obtain the intellectual property rights.

Financial assistance for science from the private sector is not wrong in itself. However, as human life is the object of research, we may ask if there is a limit to the commercialization of biotechnological research and its applications. In other words: 'How do we make the bioethical norms effective and useful?' On this, some elements for consideration have already been suggested in this paper.

Conclusion

In the face of these preoccupations and constraints, three actions may be efficient for the potential power of science. We are still taking the example of genome science here.

- First, all the information on the results of genome research should be published, because people wish to know what scientists are doing. Often people are anxious as to the process, objects and applications of scientific research. Scientists can no longer remain in their self-regulatory system and should be exposed to public awareness.
- Second, science education in general, as well as in its cutting-edge fields, is indispensable from an early age. General comprehension and recognition of science will provide more favourable conditions for scientific research.
- And finally, it is the state which has the ultimate responsibility for promoting science as a whole. Decision-makers should take appropriate steps first to establish and improve the general science policy in their country and accordingly take specific political decisions in specific fields of science.

Each country and each people has potential power. But the question is: in what way may a people take action for progress using its potential power based on its scientific potential? The ethics of science must play a key role in this peaceful battlefield for human progress. I dare suggest a tiny seed of thought, which is the concept of 'harmony'. Human progress will never be accomplished for one and all without harmony. 'Harmony' is thus the main axis of the ethics of science.

Note

1. See, respectively, Articles 2(a), 5(a) and 10 of the cited *Declaration.*

Thematic meeting report

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The topic of ethics in science loomed large at the World Conference on Science. It constituted a focal point of interest for many specialized sessions and discussions. The session on Science, Ethics and Responsibility gathered approximately 150-200 participants. It was competently prepared by the plenary lecture of Sir Joseph Rotblat. Thematically the topic was discussed from a variety of different angles: from the perspective of ethics in and for scientific practice, to perspectives of historical development of thinking about the ethics of science, to perspectives of justice in the global distribution of scientific knowledge and its benefits, to matters of social responsibility for directing the scientific effort towards beneficial goals for the good of all humanity. In spite of this variety of focus, there was an underlying agreement about the importance of increased global attention to ethics in science. It was felt that ethics may indeed prove to be among the most crucial topics for science in order to shoulder the challenges of the near future. 'Science for the new century' may perhaps be read as science with a more explicit ethical awareness and in constant open dialogue with its surrounding societies about matters of values and ethical commitment. Ethics of science would thus be seen as an ongoing and intensified global and regional project of maintaining new forums of dialogue with the public and creating trust in the enterprise of science. It also emerged from the discussion that the participants, both invited speakers and the audience, had great expectations of the two organizations which convened this World Conference on Science, UNESCO and ICSU. Together they can stimulate the decision-makers on science policy, as well as the scientific community and other organizations to work together for the realization of goals pertaining to this new challenge.

The session was most competently chaired by HE Vigdis Finnbogadottir, present chair of UNESCO's recently established World Commission on the Ethics of Scientific Knowledge and Technology (COMEST) and former President of Iceland. Ms Finnbogadottir set the stage for the discussion with a brief introduction of the topic of this session. To start with, she made particular reference to efforts preceding this meeting, such as the *Declaration on the Human Genome and Human Rights* by UNESCO's International Bioethics Committee (IBC) and the ongoing work of COMEST, which held its first session in April 1999 in Oslo, Norway. A background paper on the topic was prepared by ICSU's Standing Committee on Responsibility and Ethics of Science (SCRES) and sent to all speakers, chairs and rapporteurs of the World Conference on Science. Ms Finnbogadottir observed a certain disillusionment in certain sectors of the public about the goals and the potential of science. In spite of steady developments that push back apparent limits of our knowledge, doubts are occurring about the intrinsic beneficial function of science and knowledge. The Janus-face of science has always balanced the potential benefits with potential threats, but it is in our time that the potential threats of new kinds of knowledge, for instance about genetics and information technology, seem so overwhelming that broad concern is spreading in the wider public. While it may be an advantage to have abandoned more naïve beliefs in automatic progress, it is essential that the positive potential be retained and stressed. Science needs to be admired as a basically liberating force.

Ms Finnbogadottir put forth the three essential Ts for science: Transparency, Truthfulness and Trust. Without transparency of the scientific enterprise the basic commitment of science is threatened. Science is public knowledge. There are tendencies in present-day science that may lead to a confusion of roles. There is a limit to the extent that a scientist can remain a scientist and also become a businessman. The open communication of results, overriding possible financial interests, remains a cornerstone of the scientific enterprise. Truthfulness may be threatened when political and other interests intervene. This is often apparent in matters relating to risk, where adequate communication is essential. While zero risk may be an illusion, it is essential to find levels of acceptable risk and to discuss these with a clear exposition of the values involved. Trust is the precondition for producing useful knowledge. Without public trust, the legitimization of science is undermined. We see nowadays that trust dissolves when science overlooks basic ethical challenges. When the gaps are widening between the information rich and the information poor, or the gene rich and the gene poor, the developed and the developing countries, this is also a failure for science, and trust in the potential of science to counteract unjust developments is threatened.

A new science, a science with an explicit commitment to ethics, needs, as Ms Finnbogadottir stressed, to appreciate participatory approaches. This opens up both the internal workings of the production of new knowledge and the application of scientific and technological findings. Parliamentary technology assessment groups and ethical audits are among those participatory mechanisms that could promote a more well-entrenched ethics of science.

The increasing gap between North and South: a globalization paradox

Professor José María Cantú from Mexico and member of SCRES started his presentation by quoting the recommendations made in the SCRES[1] background paper. These are:

- a recommendation that ethics in science education be strengthened;
- a recommendation that independent national bodies for ethics in science be established;
- a recommendation that international guidelines to govern all strands of science and research be adopted;
- a recommendation that long-term science policies should be applied;
- a recommendation that an open dialogue with the general public be maintained.

Professor Cantú was particularly concerned that certain facts be more adequately accounted for in our reflections on the ethics of science. The growth in world population is both impressive and at the same time threatening. The important role that modern medicine, including preventive medicine and hygiene, plays in this development should be realized. The potential importance of the mapping of the human genome in this respect should in particular be noted. At present we are discovering approximately one gene every three hours. We can only guess what the impact of these findings will be. Yet, already we know that the potential benefits of these scientific efforts will be very unevenly distributed over the globe. In spite of all the talk about globalization, in science we rather face a development towards increased regionalization. The efforts to map the human genome include only very few contributions from Third World countries. All indicators such as publishing records, number of patents, number of scientists, etc., show that the inequalities are increasing. Thus, one lays the foundation for new dependencies between the rich and the poor, and developments counter to the ideal of equity. Science, above all other pursuits, should strive for true ‘globalization’. Professor Cantú was urging scientists to seek collaboration with a conscious view of the attempt to reduce these inequalities. He cited the collaboration between the USA and Panama with regard to human genome research as a positive example. Motives for scientific collaboration should be grounded in more than immediate expediency and similar interests. Collaboration should be grounded in a scientific commitment to equity and a globally just access and contribution to scientific knowledge. He concluded his talk with the mention of the case of the Tarahumara Indians in Mexico: instead of thanks being given for receiving a gift, the donor of the gift gives thanks for the opportunity to give.

Human cloning: the ethics of replicating us

Dr Margaret Somerville from Canada based her talk on the observation that ethics is much more than personal attitudes. It comprises the structural analysis of concrete dilemmas and cases, and seeks to elicit arguments for or against the options we face. With regard to scientific development these options may also include one to abstain from putting to use the methods we have discovered. A case to illustrate this may be the debate about cloning. She asked whether human cloning may actually be the test case where we finally, and after considering all the pros and cons, want to say ‘no’. Perhaps we will end up saying that we do see certain positive advantages in human cloning, but we still do not want to pursue that path. Dr Somerville stressed that our pluralistic values often let us focus our ethical analysis on the physical risks of interventions such as human cloning: we might agree on these risks. But we tend to exclude consideration of metaphysical risks – threats to the values, beliefs, attitudes and norms on which we base our individual and collective lives – on which we do not agree. However, it is these values that give meaning to our lives. One of the difficulties, for instance with cloning, is that the pace of making adjustments to new developments is so different in these different spheres of life. It is remarkable, as Dr Somerville said, that science time is so much quicker than ethics time. While science quickly comes to grips with exploring various physical aspects of new interventions, ethical debate typically lags behind. More specifically she contrasted science time versus medical time, business time versus political time and ethics time versus nature time. Assessing and weighing values is not a typical expert activity, it needs a broad reflection in social reality. Our ethical intuitions usually undergo a development depending upon familiarity with the issue at stake. Our moral feelings are an initial indication about what factors it is relevant to consider, but they also often move from rejection and horror to neutrality, to acceptance and finally to positive approval. She concluded that respect for the public implies not to act first and look for acceptance later. Ethics is not an add-on to development; it must always be firmly integrated in scientific development.

Science, ethics and responsibility in a globalized economy

Professor Shem O. Wandiga (Kenya) raised the question of ethics in science from an African perspective. It is known that, in order to benefit optimally from the findings of science, special institutions or 'incubators' where new knowledge can develop are needed. Universities or research institutes are among the more traditional 'incubators of knowledge'. These are supplemented by 'incubators of technology' where knowledge is transformed into goods and services for the larger public. Most developing countries place an emphasis on the former but not on the latter kind of institutions, according to Professor Wandiga. Before this additional aspect is realized, it is hard to see the scientific contributions from developing countries as fully integrated in the global scientific enterprise.

An important part of this picture is actually to establish an ethics for science. Work on these aspects has contributed to improving the practice of science. For further improvements, continued efforts need to be made to come to grips with existing ethical problems like plagiarism, mistreatment of experimental animals, lack of informed consent in human experiments or danger of environmental harm. However, Professor Wandiga noted that only a few countries have developed an ethics for science. Much needs still to be done in this respect and in certain parts of the world more than in other parts. Even the training of our future scientists may be seen as incomplete when viewed in the light of the ethical challenges that we face in areas like molecular biology or communication and information science. These are global problems that need a global strategy in order to find a good solution. He asked where we may find the actors that can prepare the ground for this.

But there is also ethics in science, in the sense of making personal choices about the paths to pursue in our research. Particularly important are choices pertaining to sharing our findings with the scientific community at large. Professor Wandiga described the ongoing debate about patenting scientific results and intellectual property rights as a potential threat to the spirit of science. Should the interests of a few developed countries in this respect count more than the interests of the developing countries? As a final note he asked the audience to consider where we would have ended up if eminent scientists like Louis Pasteur had chosen to patent their findings.

The precautionary principle

Professor Bizerka Belicza (Croatia) took up the question of the precautionary principle. This principle has found an eminent expression (among others) in Article 15 of the *Rio Declaration* of 1992:

> 'In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.'

A matter of fundamental importance is whether this principle impacts only decision-makers and administrative bodies or whether it also affects science and the scientists. In this context, Professor Belicza made reference to Thomas More's *Utopia* of 1516. Here an ideal commonwealth was put forth as a possibility, based upon advances in science and technology. Francis Bacon, in his *Sylva Sylvarum* of 1627 followed suit and made the then most daring predictions (or rather prophecies?) of what might result from this advancement of knowledge (prolonging life, curing diseases that are believed incurable, making new species, transplanting one species into another, etc.). From a modern perspective, however, these early daring predictions and fantasies read like a summary of some present-day research programmes. What was unthinkable earlier has become reality; the utopian character is lost.

Science will always be at the forefront of such development. That is why science is much more than the personal interest and passion of a few dedicated explorers and scientists. Modern science is a powerful and socially well-organized production of new knowledge and technology, aimed at a rapid transformation into applications. Thus, it is primarily the scientific community that has the responsibility to start early and timely reflections on the pros and cons of new knowledge. It is the scientists who are uniquely placed to address issues of precautionary and preventive action. The question of good scientific practice is thus a problem of addressing precautionary practice.

It is noteworthy that the issue of ethics of science has been primarily addressed in the medical sciences. Professor Belicza saw this as indicating only the tip of an iceberg. Other sciences are lagging behind in this respect, but are still no less in need of ethical reflections. She mentioned that the suggestion of Joseph Rotblat to institute a scientific oath in line with the Hippocratic Oath, or a universal code of conduct for science, was very much in line with her thinking about the issue.

Scientific power, economic power, political power

The last speaker, Professor Ryuichi Ida (Japan), stressed a difference between ethics for the sciences and ethics of scientists. Both need our attention. Three important issues need to be realized when discussing the ethics of science:

- modern science has made tremendous progress in communication and information exchange across the whole globe (our Earth has truly become one);
- science and technology impact directly on the economic power of countries;
- genomic research is preparing the ground for the possibility of extensively controlling and steering many aspects of human life.

All these areas raise considerable ethical challenges and these must be addressed not only by scientists but also by the media, decision-makers and industry. However, it is also necessary to acknowledge that the basic precondition for scientific progress is the freedom of the individual researcher. This scientific freedom consists, according to Professor Ida, of three essential aspects:

- the independence of scientists (of funding agencies, industry, etc.);
- the material environment fostering research activities;
- the social recognition of the work bestowed upon the scientists by society.

The research on the human genome can in many ways serve as an example of the complexities of the ethical challenges. Here it has been realized that it is necessary to utilize competence from various fields and disciplines, including the social sciences and humanities, in order to come to grips with the ethical challenges that lie in the possibility of manipulating the human genome for various purposes. Bioethics is indispensable in this respect. The UNESCO *Declaration on the Human Genome and Human Rights* sends important signals for future developments in this field. These are truly steps in the right direction, but it may be necessary to state three rules for scientific practice that could be essential if research on the human genome is to make a positive contribution to mankind:

- all information and all new findings on the human genome should be made publicly available as soon as possible;
- science education should start at an early age, foster an interest in science and in the long run provide more favourable conditions for science;
- states should recognize their responsibility for providing the necessary framework to explore new scientific possibilities and to discuss their ethical aspects in depth and in their full breadth, including with the public.

Professor Ida concluded his presentation with the observation that, from his point of view, the principle of harmony should be seen as the central principle of all ethics, including the ethics of science.

The speakers had the possibility to follow up on some of the above points during the discussion with the audience. In spite of occasional critical remarks or comments on some points, it is the rapporteur's clear impression that both the speakers and the audience were united in a common recognition of the importance of the subject for the science of the 21st century. They all seemed to agree that it is to be hoped that this discussion will be continued by other people or organizations that will develop appropriate forums to address the ethical challenges of science.

Note

1. The background document may be accessed at: http://www.unesco.org/science/wcs/background/ethics.htm

THEMATIC MEETING I.12 SCIENCE AND ENERGY

Energy policy: strategy and challenges for the future – a technology perspective

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The global imbalance in energy supply and demand coupled with the environmental consequences of emissions is causing mounting concern for the sustainability of our development future. One answer to this predicament is to find appropriate solutions based on the systems options, incorporating advanced technologies, which can help to overcome energy and environmental constraints while also maintaining sustainable development.

While research and development (R&D) investment has become increasingly more expensive and difficult to sustain, a dramatic increase in the transboundary flow of people, goods, money and information, together with an increase in technology complementarity with capital stock and labour forces, has accelerated the growth and spread of global technology spillovers.

Under the circumstances, in addition to extensive efforts to maintain sustainable R&D investment, a substitution of technology from the global marketplace for indigenous R&D investment has become an important strategy leading to greater concern for assimilation capacity (the ability to utilize this spillover technology) for sustainable development.

On the basis of this understanding, this paper focuses on two dimensional systems options:

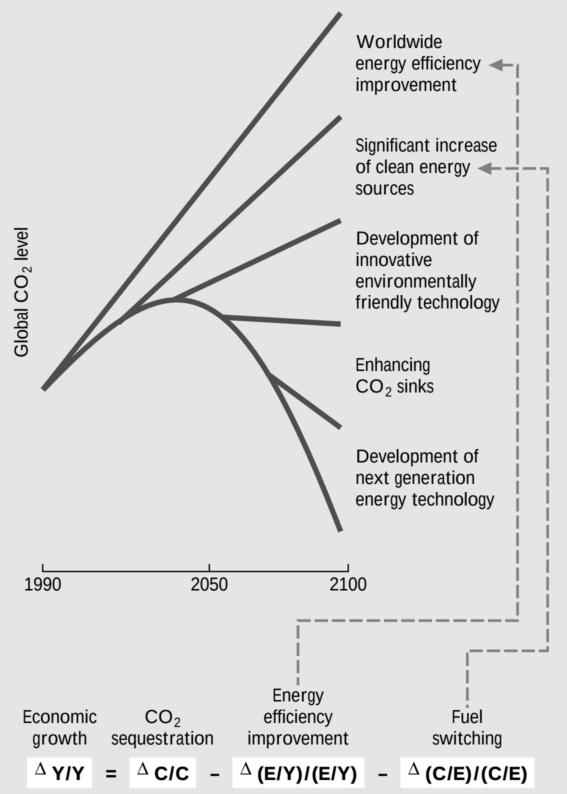
- systems options identifying the most appropriate R&D investment for restoring global environment conditions;
- systems options aiming at maximizing systems efficiency through not only R&D investment but also through stimulating mutual interaction between the learning exercise, assimilation capacity improvement and effective utilization of technology spillover.

Systems options for appropriate R&D investment

New Earth 21: the review of the future of energy technologies

New Earth 21 (Action Program for the 21st Century), proposed by Japan in 1990, encompasses comprehensive and long-term systems options over the next century aiming at restoring global environmental conditions to a level equivalent to that before the Industrial Revolution in the 18th century and suggests possible progress towards 'no-regret' options (Figure 1).

Figure 1. **General concept of New Earth 21**



In light of the increasing significance of the identification of the most appropriate systems options, a general review of the future of energy technologies on the basis of the concept proposed by New Earth 21 was undertaken. On the basis of such a review, the Committee on Energy Research and Technology (CERT) of the International Energy Agency (IEA) analysed the subject of how science and technology could be mobilized to help IEA member countries meet the commitments entered into at Kyoto in 1997. The results of this study were reported to the IEA ministerial meeting in May

1999. These reviews of future energy technologies contributed to identifying the most appropriate systems options under complicated circumstances.

Key dimensions of energy technology strategies for the 21st century

Systems dimensions The above reviews undertaken from the systems options perspective suggest that, given consistent efforts and reasonable sustained government initiatives, energy technologies in the major categories, particularly technologies in the categories of end-use energy, renewable energy, nuclear fission and cleaner use of fossil fuels, prove to be technically good prospects with sufficient potential for market compatibility. Substantial points for attaining the New Earth 21 goal by ensuring such a prospect depend on systems dimensions rather than individual technical dimensions. One critical requirement is an effective mechanism for inducing innovative technological breakthroughs and international spillovers from these breakthroughs. That is, the success of this initiative requires a timely construction of both a virtuous spin cycle between technology in its social, economic and natural environments in a global context, and a system for maximizing potentiality, biased towards particular countries/regions by global technology spillover.

Global complementarity Another important finding obtained from the above review is that global complementarity is indispensable for attaining the New Earth 21 goal. The systems options for overcoming energy and environmental constraints while also maintaining sustainable development can be simply considered a dynamic interaction of 3Es: economy, energy and environment. Provided that these 3Es can be represented by production (Y), energy consumption (E) and carbon dioxide (CO_2) emissions (C), such a dynamic game can be represented by a simple equation illustrated at the bottom of Figure 1. Thus, an appropriate option based on the systems solution to the above proposition is to find a best combination of the three possible options: energy efficiency improvement, fuel switching and CO_2 sequestration. The above reviews suggest that, if the expertise and experience of particular countries/regions with comparative economic, geographical and/or social advantages could be transferred to other countries/regions with comparative disadvantages, the 3E conditions of recipient countries/regions could be dramatically improved leading to global improvement in the 3Es. New Earth 21 is navigating long-term systems options over the next century by demonstrating energy/environmental technologies corresponding to the above options.

Systems options for maximizing systems efficiency

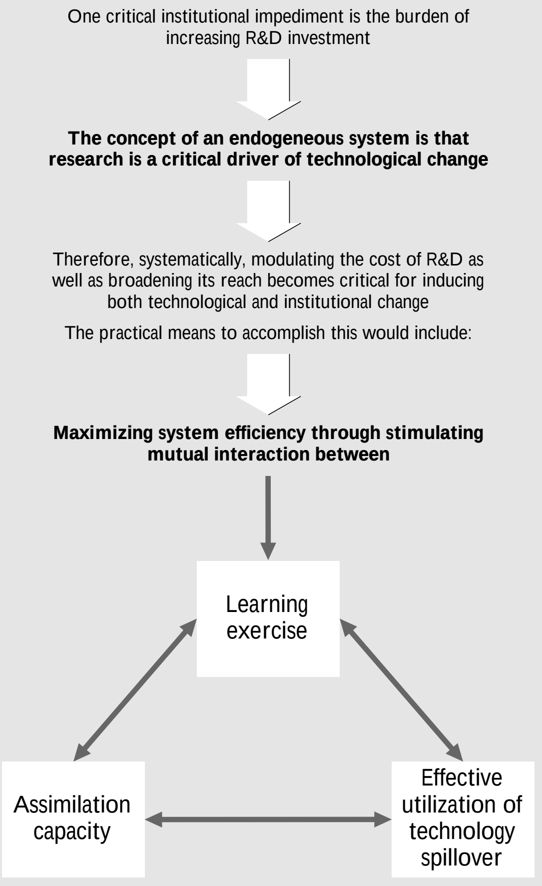
Global learning and spillover

Efficient global learning is linked to technology spillover and both have mutually stimulating interactions. Thus, technology spillover not only alleviates some of the burden of huge R&D investment but also enhances the learning exercise involved in assimilating environmentally friendly technologies and processes. Efficient global learning improves the quality of technology, accelerating technology diffusion leading to socio-economic development. This development results in scarcity of energy and environmental capacity, which induces further technology development and thus creates a virtuous cycle between R&D, assimilation of technology, energy efficiency improvement and socio-economic development.

Critical systems option

One critical institutional impediment is the burden of increasing R&D investment. The concept behind an

Figure 2. **Critical systems options for induced technology development in the energy/environment sector**



endogenous system is that research is a critical driver of technological change. Therefore, systematically modulating the cost of R&D as well as broadening its reach becomes critical for inducing both technological and institutional change. The practical means to accomplish this would maximize systems efficiency through stimulating mutual interaction between the learning exercise, assimilation capacity improvement and effective utilization of technology spillover (Figure 2).

This concept is particularly important from the often-neglected perspective of developing countries.

Implications for techno-economics

Key messages obtained from the above review for energy policy could be summarized as follows:

- systems dimensions are crucial for energy technologies to attain the sustainability goal;
- global complementarity is indispensable for attaining the goal;
- stimulation of global learning linked with technology spillover will play a significant role;
- construction and maintenance of a virtuous cycle thereon would be crucial.

Important suggestions based on the systems options viewpoint can be summarized by the following:

- the subsequent creation of a virtuous cycle has promising policy applications in terms of induced technological change and the environment;
- it demonstrates not only critical success factors in altering technology trajectories but also illustrates a successful case of policy, market and R&D working together to accomplish this;
- there exist important network externalities or technological interrelatedness even in endogenous technological innovation processes;
- it is important to consider and coordinate technology networks as a technology policy issue;
- of particular importance is interpreting and moving market signals rather than just creating them from a policy perspective.

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Distributed power: a challenge for the 21st century

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The electricity supply systems common in the developed world today were conceived 50-60 years ago, at a time when they were considered a subject for public interest and control. Much electricity was generated from coal and the primary objective was to maximize electrical generation efficiency to reduce cost. Based on the technology of the day the optimum solution was to centralize generation close to the source of fuel and/or the essential heat sink. The energy was transmitted as electricity at high voltage (to minimize losses) on overhead air-insulated cables to minimize costs. Environmental concerns were limited to the deposit of combustion ash and were resolved by building high chimneys so the problem was literally blown away in the wind (unfortunately, often to a neighbouring country).

Changing environment

During the last few years changes in a number of areas suggest that this classical model may no longer be optimal. The changes include the following.

Deregulation

There is a clear move in several parts of the world to liberalize and deregulate the electrical supply industry. This opens the market to competition in supply to replace the traditional monopolies. The several suppliers are free to choose their own technical offerings and try to better meet customer desires by including innovative and value-added services. As commercial organizations they are sensitive to the cost of financial capital and thus to both first cost and construction time of equipment.

Environment and politics

There is presently great political sensitivity to environmental impacts and global warming, reflecting a general public concern. The political action is manifested in the Kyoto

Protocol which will impact greatly on electrical supplies, which represent almost half of the emissions covered. Due to the sensitivities it is reasonable to expect both regulatory action and a customer awareness which will make environmentally benign energy a discriminated product.

Natural gas

Twenty years ago natural gas could not be used as a base load industrial fuel. Increasing discoveries which have continually augmented the distributed reserves (now at 70 years – or two generations of power equipment) encouraged a European accord to release it as a fuel. It is the 'cleanest' fossil fuel as it contains the highest ratio of hydrogen to carbon and thus the lowest ratio of carbon dioxide to water for a given energy release. Unlike coal and oil it is virtually uncontaminated by sulphur, heavy metals and other elements producing noxious emissions. It is also easily distributed through an existing infrastructure of pipelines.

Technology advance

Recent technical progress has provided capabilities that were unknown when today's electrical supply architecture was conceived:

- *Computers:* extremely high-powered computers are now available at very low cost and in compact packaging providing the potential to install intelligence in individual components and thus sophisticated control of complex and dispersed systems.
- *Power electronics:* now available at reasonable cost to dynamically control AC electrical wave forms offering unprecedented flexibility in connecting generators to electrical systems.
- *Fuel cells:* electrochemical devices that transform fuel directly into electricity without combustion or a conventional generator. Consequently, they are near-zero emission systems.
- *Micro-turbines:* a new design of sub-1MW generators based on gas turbine technology offering a low-cost, simple, low-emission system.

Distributed power

With the challenges in the commercial and political environments described above and the technology development described, the optimum solution available today appears to be a distributed power concept as opposed to the classical centralized electrical system. The new approach would transmit energy as fuel (natural gas or even hydrogen) in existing pipelines then convert this to the energetic form (electricity, heat or even refrigeration) at the point of use.

It has only recently become possible to do this practically while maintaining a reliable and assured supply to a large number of consumers. It has not yet been done to any great extent due to the large (and expensive) electrical infrastructure of market liberalization. It should also be noted that some of the required technologies, although technically demonstrated, require further development to be commercially competitive.

The major advantage of distributed power is that the local conversion of the fuel makes it practical and economical to employ co-generation (using both the electricity and the thermal energy produced by the conversion) and this immediately increases the efficiency of fuel utilization to around 85%. This compares with the typical 55% of the best central power generation technology available today. It is also true even in well-established generation equipment such as reciprocating engines, etc.: with co-generation the technology of generation influences only the proportion of electricity to heat and the level of emissions.

Renewable energy

There is a strong desire to increase the utilization of renewable energy – solar photovoltaic, wind, wave, etc. Within the existing power system the relatively low energy density of these sources makes them uneconomic unless they are located adjacent to a user. Even if they are close to the user, however, there is a further problem which is their inherent unreliability. It is not possible to guarantee that the sun will shine, the wind will blow or the sea will be rough and some means of stabilizing the output is essential. At present the electrical system dynamically compensates for variations in output (and charges handsomely for providing the services).

Clearly, the distributed nature of renewable energy is well suited to a distributed power system and in my view will be more widely exploited when such a system is available and an efficient means of storing electrical energy is developed to cope with the varying availability.

The technical challenges

In spite of the progress made there remains significant potential to improve the elements of the electrical system. Virtually all the devices described in this paper use 19th century science implemented in 20th century technologies. The technology can be further improved in the 21st century but even more we need to improve some of the underlying science.

Energy conversion

- *High-efficiency solar photovoltaic:* existing systems are around 10% efficient. A higher efficiency of energy conversion would dramatically improve usability and effectiveness.
- *Electrochemical catalysts:* a key component of the fuel cell systems currently being developed, their improvement to extend the range of fuels handled and their tolerance of contaminants would yield enormous benefits.
- *Hydrocarbon gasification:* coal remains the planet's dominant energy source but as noted above is unsuited to distributed power systems. Existing means of converting it to gaseous fuel requires large systems of modest efficiency. A more advanced system (such as biotechnology?) would bring great benefits.

Reliability

- *Sensors:* for distributed systems, remote monitoring will be critical to overall reliability and, in turn, this will depend on effective sensors. Today's technology monitors classical parameters such as temperature, pressure and in some cases chemical species, voltages, currents, etc. A means of measuring directly the fundamental parameters that control reliability would be invaluable – insulation integrity, electrochemical activity, etc.
- *Health monitoring:* an effective means of condition assessment of highly dispersed large systems is still an undeveloped technology. It offers a field where the new science of complex theory may find an application.

Energy storage

- *Electrical:* we still have no science for the economic and efficient storage and retrieval of electrons at the MW scale. Until we do, renewable energy will remain a niche curiosity.
- *Non-electrical:* with a distributed power system the conversion capability is widely spread so it would be possible to consider energy storage in other forms as long as these were sufficiently compact.

Power control

- *Control:* in spite of the success of power electronics, existing systems remain fairly expensive and a cheaper way to dynamically control wave forms is still needed.
- *Systems:* probably the Internet will remain the largest and most complex system devised by man. But a reliable power supply system involving many distributed conversion and control devices represents an enormous challenge from the control viewpoint. We need a way to handle and manage a complex system affected by many intelligent agents (the users and the components) without a central control function.

Concluding remarks

The established electrical system has worked reliably and is a triumph of engineering technology. It can be improved upon even with today's technology but this will require the replacement of an existing and expensive infrastructure. It will not be done overnight and it is conceivable that existing interests may inhibit it ever happening.

If it does happen, it offers the potential to effect a major reduction in our impact on the environment and, with the resolution of the scientific barriers discussed earlier, to open the door to a real exploitation of renewable energy.

The role of science in the development of fission and fusion energy

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The effective development of new nuclear-energy technologies, such as advanced fission reactors, accelerator-driven systems and nuclear fusion energy, and the safe maintenance of existing technologies rely on a thorough understanding of the relevant physical and chemical processes. As discussed below, there exist very close links between nuclear physics and nuclear fission power development and between atomic physics and the development of nuclear fusion energy.

Case history: nuclear fission

The historical development of nuclear fission may serve to illustrate the interplay between science and nuclear energy. The 1930s were a period of almost continual discovery in the young field of nuclear physics. In 1932, J. Chadwick discovered the neutron, an electrically neutral fundamental particle. In the mid-1930s, E. Fermi discovered that a non-absorbing 'moderator' such as graphite could be used to slow energetic neutrons down to thermal energies (0.025eV). Neutron irradiation of the heaviest known element, uranium, in the search for even heavier elements, led in 1939 to the accidental discovery by L. Meitner and O. Hahn of nuclear fission, a previously unknown event in which a heavy nucleus splits into two light fragments (fission products). Within months, Fermi and L. Szilard showed that 2-3 'new' neutrons are released in fission and N. Bohr realized that the observed fission of uranium by slow neutrons must be due to the rare isotope ^{235}U (0.7% of natural uranium). All of these scientific insights were crucial to the successful design and operation of the world's first self-sustaining fission reactor in 1942.

After the Second World War, there followed a period of steady growth in peaceful applications of nuclear technology and in 1957 the International Atomic Energy Agency (IAEA) was established, in order to assist in the necessary scientific and technological developments and to provide international oversight. Among the scientific activities supported and coordinated by the IAEA from the early days up to the present is the collaborative international effort to measure nuclear physics data relevant to nuclear technology and the international compilation, evaluation and dissemination of the numerical results (Nordborg *et al.*, 1998).

In the relatively short time that has passed since the groundbreaking scientific discoveries of the 1930s, nuclear fission has matured into a reliable and economical source of electrical energy. There are now 434 nuclear power plants in operation in 31 countries, satisfying 16% of the world's electrical energy demand (Anrade *et al.*, 1999). In the developed member countries of the Organisation for Economic Co-operation and Development (OECD), the installed nuclear-generating capacity is expected to grow slowly (about 1% per year) over the next 12 years (NEA, 1999). In some regions, more rapid growth is expected, with three or more new nuclear power plants currently under construction in China, India, the Republic of Korea, the Russian Federation, Slovakia and the Ukraine (IAEA, 1999).

Although not, strictly speaking, a 'renewable' energy source, the resource potential of nuclear fission is large. Fission also belongs to the class of attractive energy sources (along with solar, hydroelectric and wind energy) not based on the combustion of fossil fuels. It is estimated that, by displacing fossil-fuel power plants, nuclear energy avoids the emission of some 2 billion tonnes of carbon dioxide (CO_2) per year (Van de Vate, 1998), which is comparable to the CO_2 'sink' provided by all forests of the Northern Hemisphere (IGBP, 1997).

With the rapid growth of economies in many countries and with the finite capacity of the ecosystem to absorb the combustion products from fossil fuels, the world's need for abundant, economical and environmentally benign energy is becoming even more urgent. Below we present examples of the vital role that scientific research can play in developing innovative approaches that will allow nuclear fission energy to reach its full potential in helping to meet this need.

Radioactive waste

In the burning of carbon-based fossil fuels, all of the combustion-product CO_2 and a portion of the mineral waste (ash) are released directly into the atmosphere. By comparison, nuclear waste is retained naturally within the discharged 'spent' nuclear fuel. Many components of the waste, including ^{60}Co, ^{90}Sr, and ^{137}Cs, have half-lives of 30 years or less and, with the passage of sufficient time (several half-lives), these isotopes decay into stable, non-radioactive products. Unfortunately, some fission products, such as ^{99}Tc, ^{129}I and ^{135}Cs have lifetimes in the order of a million years. The situation is further complicated by the build-up of long-lived isotopes of the transuranic elements neptunium, plutonium, americium and curium during power generation. The intensity of the radioactive emissions from long-lived waste is relatively low, but waste isolation on a geologic time scale would be required for this radioactivity to decay to truly negligible levels.

This situation has led to exciting research work on accelerator transmutation of long-lived radioactive waste (Arkhipov, 1997; Venneri, 1998). In this approach, a high-power proton accelerator would be employed to create an intense neutron source for the purpose of destroying, by means of nuclear 'transmutation' reactions, most of the long-lived waste from fission reactors. It may even be possible to optimize the overall system to the point where the radiotoxicity of the wastes at the time of disposal is less than the radiotoxicity of the fuel materials originally extracted from the Earth's crust. Such optimization studies require (in addition to data for the traditional nuclear materials such as ^{235}U, ^{238}U and ^{239}Pu) a more accurate determination of the neutron-interaction cross-sections of a large number of transuranic and fission product isotopes. For such accelerator-driven systems, the neutron energy range of interest extends well above the 0-10MeV range important in conventional reactors.

At low energies, protons interact primarily with the atomic electrons, so that much of the proton energy is dissipated as local heat. However, above a few hundred MeV, these electronic interactions become increasingly suppressed, so that the efficiency for the conversion of proton energy into nuclear events (such as neutron production) rises dramatically. For example, when a single 1 600MeV proton strikes a massive block of lead, around 50 neutrons are produced (Lone and Wong, 1995). The development of a cost-effective accelerator facility for the transmutation of waste also will require high efficiency in the conversion of electrical energy into proton energy. This will, in turn, require large-scale application of another discovery of 20th-century science, electrical superconductivity.

Although we have spoken mainly of physics, nuclear chemistry will also play a vital role. For example, in the area of ‘waste partitioning’, sophisticated chemical processing is required for the removal of heavy elements and long-lived fission products from spent nuclear fuel (Sood and Patil, 1996) and their incorporation into new nuclear fuel for energy production and targets for waste transmutation.

Advanced reactors

Developments in nuclear data and reactor physics over the past 60 years allow the nuclear fission reactor designer of today to pursue new initiatives (Mourogov, 1997). For example, several designs have been put forward for systems with greatly improved inherent safety. These designs often include physical barriers (such as a large integral heat reservoir) designed to prevent future occurrences of serious accidents such as the one at Chernobyl.

A completely different approach to the design of power plants with greater inherent safety is to use an external neutron source to ‘drive’ a fission reactor that remains well subcritical even during full-power operation (Arkhipov, 1997; Venneri, 1998). As mentioned above, a 1 600MeV proton can be used to generate around 50 neutrons in a lead target. If these neutrons are introduced into a subcritical fission reactor with a neutron multiplication of 20, the total energy released in the fission reactor will be around 110 times the initial proton energy. Only a small fraction of the electrical output of such a subcritical power plant would need to be recirculated to sustain the proton beam.

Another promising line of research is the development of fission reactors based on the consumption of thorium rather than uranium. The thorium fuel cycle is expected to have improved non-proliferation characteristics and it largely avoids the production of long-lived transuranic waste (resulting from multiple neutron captures on ^{238}U) by eliminating ^{238}U from the reactor core. Improved nuclear data are needed in the region of ^{232}Th and ^{233}U, which offers another opportunity for the nuclear physics community to contribute to technological advances in the energy field. As in the case of waste transmutation, the development of new fission-reactor fuel cycles will also necessitate further work in the field of fuel-cycle chemistry.

Nuclear fusion

An example of a different kind of role for technical innovation is the large, international effort (ITER, 1998) to develop nuclear fusion (the joining of nuclei of light elements) into a practical new source of energy. Clearly, fusion is full of promise, but we have yet to reach the stage of building a self-sustaining fusion reactor. In short, we are still in the ‘discovery-and-development’ mode. One example of this continuing process is the invention and development of the poloidal magnetic divertor. The idea of the poloidal magnetic divertor is to divert the radial flow of plasma heat and particle impurities into a separate chamber (divertor) located outside the main plasma volume. As originally conceived, the diverted heat and impurities are deposited onto the material surfaces of the divertor. However, the projected high heat loads (30-40MW/m^2), the rapid thermal cycling and the high rates of surface erosion of the divertor all present large design challenges.

Recently, it has been discovered that the divertor function can be performed by an ‘island’ of relatively cool plasma hovering at a stable position inside the plasma vessel, detached from the plasma-facing wall. Nearly all divertor-related material damage concerns are thereby eliminated. Science is playing a vital role in this development. First, the plasma physics of cool plasmas is much more complex than the physics of fully ionized plasmas and it requires more accurate data for a wider range of atomic and molecular interactions. The cooling of such a detached divertor is achieved purely by photon emission, either as *bremsstrahlung* or from atomic transitions, so that accurate photon-emission data are required for a wider range of atomic transitions.

Just as in the example of accelerator transmutation mentioned above, the transformation of today’s magnetically confined fusion plasma devices into cost-effective power plants of the future will require large-scale application of electrical superconductivity. The discovery of a practical ‘room temperature’ superconductor would provide an additional large stimulus to the development of nuclear fusion as a practical power source.

Outlook

Although most of the electric power plants presently under construction are based on the burning of fossil fuel, this energy solution faces rising public concern over the environmental impact of the associated emissions, such as CO_2 (global warming) and sulphur dioxide (SO_2) (acid rain). Another concern is the security of energy supply, an issue raised by the uneven distribution of fossil-fuel resources. This suggests that newly designed nuclear energy systems (advanced fission reactors, accelerator-driven systems and fusion reactors), along with renewable energy technologies, may become very important in the next century. The future role of nuclear power is the subject of a Scientific Forum at the 43rd General Conference of the IAEA in Vienna, Austria, during the week of 27 September 1999. Although one cannot predict the methods of energy generation that will be selected in the end, clearly science has a crucial role to play in the development of the promising fission and fusion energy concepts of today into practical energy options for tomorrow.

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The role of science, engineering, economics and environment in the energy system of the 21st century

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Science is the forerunner of new ideas and fresh concepts for the energy system. The last few centuries have given us a framework that characterizes the energy system, such as laws of motion, laws of thermodynamics, electro-magnetism, and so on. Stalwarts like Newton, Boltzman, Maxwell, Faraday, Carnot and others have given us the foundations characterizing the energy system. In the 20th century, we have had new discoveries that could expand options for the energy system such as the photoelectric effect, which provides the basis for photovoltaic technology, the nuclear chain reaction that gave us nuclear power, superconductivity, which has the potential to advance every aspect of the power system, viz. generators, transmission and storage, and so on (Pai and Parikh, 1989). Which scientific ideas are realized in practice? Why? Techno-socio-economic and environmental criteria determine the choices within the energy system. We could observe that, in some cases, the gap between discovery and commercialization of technology has been small, say 10 years, and in some cases nearly half a century.

The energy system and market penetration of technologies

It is important first to observe the nature of the energy system, which begins with primary energy sources which may be a gift of nature such as sun, wind or fossil fuel resources. The conversion technologies give us options to convert from one energy form to the other such as solar, hydro- or nuclear energy to electricity. Transportation and transmission have gone through major changes over the century. After final energy is paid for, there are a host of innovations in end-use devices that have come onto the market that increase useful energy derived from the final energy. Due to technological progress, every aspect of the energy system, from primary energy to useful energy, is changing rapidly with time, reducing losses and expanding options for energy systems. Technologies which have bottlenecks in any of the above steps are not likely to penetrate fast. For example, up to now, hydrogen has been difficult to store and transport. At times, two technologies together succeed better than one alone. For example, lighting with photovoltaics has penetrated faster since the advent of compact fluorescent lamp technology, which consumes less energy.

Thus, new technological and engineering acumen transform scientific concepts into tangible products and processes. However, increasingly, socio-economic criteria are playing a major role in the selection of energy alternatives. Energy prices, however arrived at, determine social choices.

Many of the desirable changes, such as improving efficiency of conversion or end-use devices, take place only if the energy resources are correctly priced. Recently, financing energy expansion has been a major problem, especially in the developing countries where capital is scarce.

Environmental concerns and role of energy efficiency

In the last two decades, local environmental concerns have become critical in making choices. To this, one adds global environmental concerns that call for a reduction in the use of fossil fuels to limit greenhouse gases so as to mitigate climate change.

Decarbonization of the energy system may gradually become a major criterion for choosing various elements of energy systems as the implementation of the Framework Convention on Climate Change progresses. Pollution, whether local or global, depends on the type of energy used and pollution emitted per unit of energy use, energy used per gross domestic product (GDP), GDP per capita and population (Parikh, 1994) (see Figure 1).

Since all countries wish to increase their income, reduction in pollution can therefore be achieved mainly by reducing the first two factors, viz. pollution intensity and energy intensity of GDP. When population stabilizes, there is more scope to arrest or reduce growth rates of pollution and energy. Technological progress combined with economic considerations reduce energy used per value added. As shown by Nakicenovic *et al.* (1998), during the initial process of development, commercial energy substitutes non-commercial energy, viz. fuelwood and agriculture residues, and therefore commercial energy appears to increase, but when both commercial and non-commercial (traditional) energy are combined, energy intensity goes down with time even in the developing countries. Therefore, the decline is sharp after such substitution has occurred.

Figure 1.

$$\text{Pollution} = \underbrace{\frac{\text{Pollution}}{\text{Energy}}}_{\text{Pollution intensity of energy system}} \times \underbrace{\frac{\text{Energy}}{\text{GDP}}}_{\text{Energy intensity of economy}} \times \underbrace{\frac{\text{GDP}}{\text{NOP}}}_{\text{Income per person}} \times \underbrace{\text{NOP}}_{\text{Number of persons}}$$

To reduce the first two factors, a number of initiatives have been commenced, such as demand-side management to reduce energy demand, fuel switching to reduce pollution, new technologies and processes that require less energy, and so on. Here, science and engineering play a major role. Power plant efficiencies, which are still in the range of 20-30% in developing countries, have reached 40-60% for the new generation of power plants which recover and reuse waste heat.

Energy and equity

Parikh *et al.* (1991) show that distribution of energy across countries and income groups is far from equitable, 75% of energy resources being used by 25% of the world population in the developed countries. Within low-income developing countries, too, the rural poor use much less energy and a large portion of it comes from locally available biomass. In particular, it is a poor woman who gathers fuel, processes or converts it, transports it and cooks with it, which entirely represents a single-person energy system (Parikh, 1995).

Murthy *et al.* (1997) have shown that in India the rural poor and the urban rich emitted 0.054 tonnes and 0.656 tonnes of carbon per person respectively (Table 1).

It is indeed unfortunate that, even in the 21st century, millions of women will be spending hours gathering biofuels, travelling many kilometres carrying them, suffering health effects of the smoke and also exposing their children (Smith, 1996).

The economic imperative and institutional changes

Along with engineering efficiencies, economic efficiency needs to improve. For this purpose, energy system institutions have seen revolutionary changes, especially in the last decade or so where big government involvement in the coal, petroleum and power sectors has been paving the way for

Table 1. **Per capita annual energy use (direct and indirect) in India 1989-90**[1]

Income group	Coal Kg	Oil Kg	Electricity kW	Carbon tonne
Rural				
Bottom 50%	74	22.5	95	0.054
Middle 40%	127	39.7	152	0.093
Top 10%	262	89.8	284	0.204
Urban				
Bottom 50%	130	45.6	164	0.101
Middle 40%	302	118.6	366	0.246
Top 10%	765	332.3	858	0.656
EDR[2]	10.3	14.8	9.0	12.0

1. Excluding energy used directly and indirectly to make deliveries to other than private consumption.

2. EDR = Extreme disparity ratio between the richest class and the poorest class.

private sector enterprises. Erstwhile vertically integrated utilities may now be reinforced by distributive energy systems. Power generation, transmission, distribution and marketing, and banking may be done by separate companies. Exploration, production, distribution and retail marketing of fossil fuels may follow the same pattern.

The energy system in the 21st century

From the above arguments, the transition of the energy system in the next century could be characterized as follows:

- from low/medium efficiency to high efficiency;
- from a fossil fuel-based to decarbonized system;
- from an environmentally damaging to an environmentally friendly system;
- from inequitable to equitable;
- from highly dependent on the public sector and government to greater participation from the private sector;
- from a highly centralized system to a distributed energy system.

One hopes that once again science and engineering will come forward to meet the challenges arising from the required transition.

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Challenges for R&D in renewable and solar energy technology

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A year ago Shell presented its ‘dream’ vision (Figure 1). It extends far into the next century and predicts a share of renewable energy of more than 50%. Only our grandchildren will know whether it is a vision or just a dream.

Visions are not self-fulfilling. A look at the current situation (Figure 2) makes clear how far we still have to go. The results of research and development will determine how long it takes us to reach this objective. Increasing efficiency and reducing manufacturing costs are the focal points of the relevant programmes.

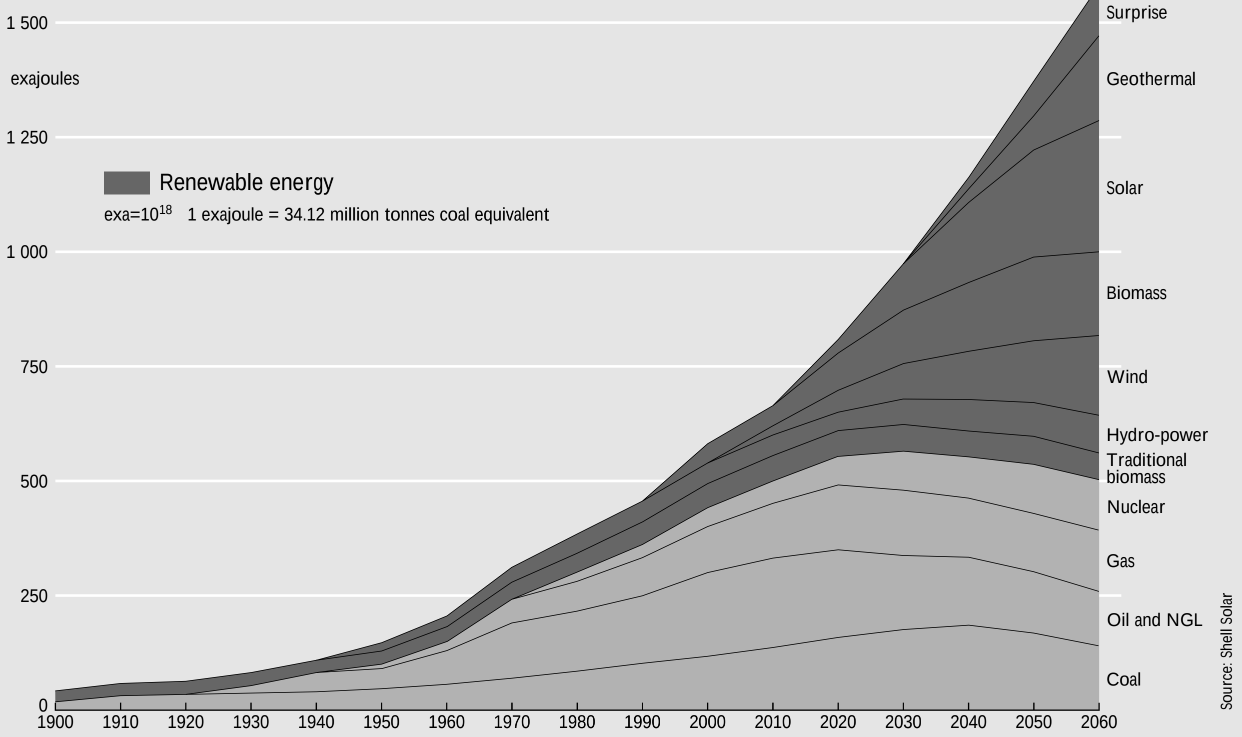
There is not enough time to discuss all types of renewable energy technologies here. I shall use photovoltaics (direct conversion of sunlight into electrical energy) to describe possible developments.

Photovoltaics currently has around a 0.007% share of worldwide electricity generation. Growth over the last 10 years has averaged approximately 15% per annum (Figure 3).

State-sponsored marketing programmes have brought disproportionate growth in industrialized countries (Japan and Germany for example). The share for grid-connected systems has therefore almost doubled to 36% over the past three years (Figure 4). This has primarily occurred at the expense of rural electrification in developing countries. The financial crisis in Asia and the economic problems in Africa and South America have contributed to this development.

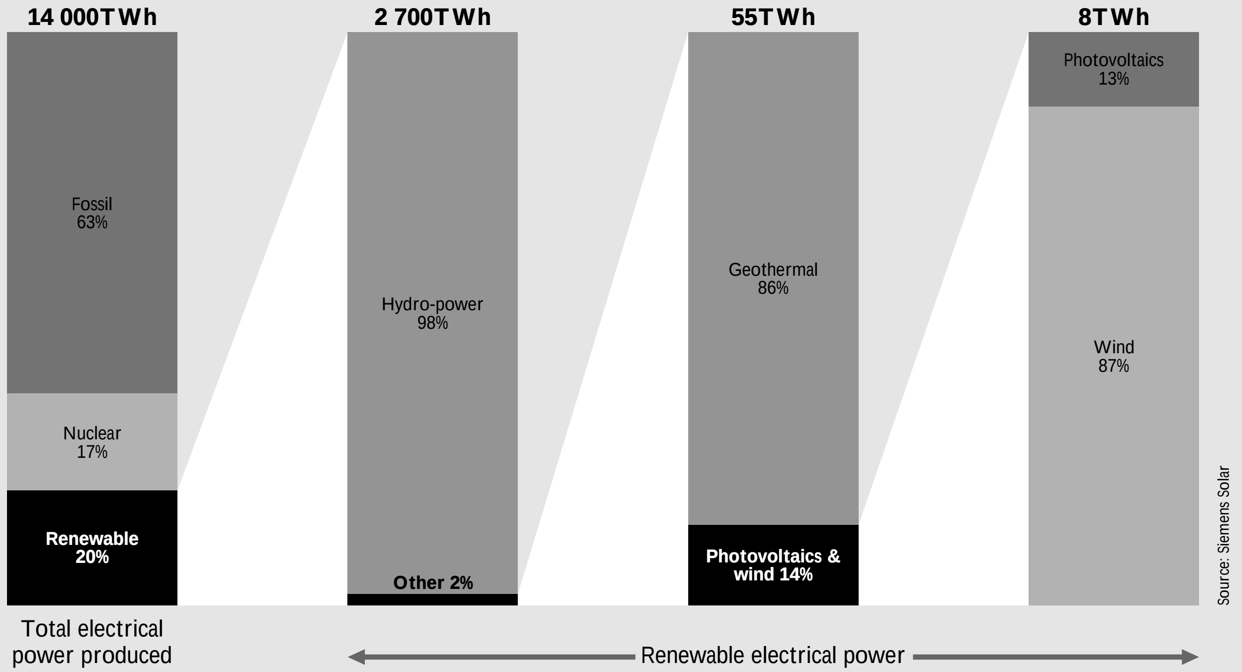
For applications remote from the grid, solar power is already a competitive, environmentally friendly and low-maintenance solution. For wide use in areas with full-coverage

Figure 1. **World energy consumption up to 2060**
Scenario: sustained growth



Source: Shell Solar

Figure 2. **Worldwide power generation, 1998**
Total: c. 14 000TWh (14 000 billion kWh)



Source: Siemens Solar

Figure 3. **Growth models for photovoltaics vs total electricity generation**

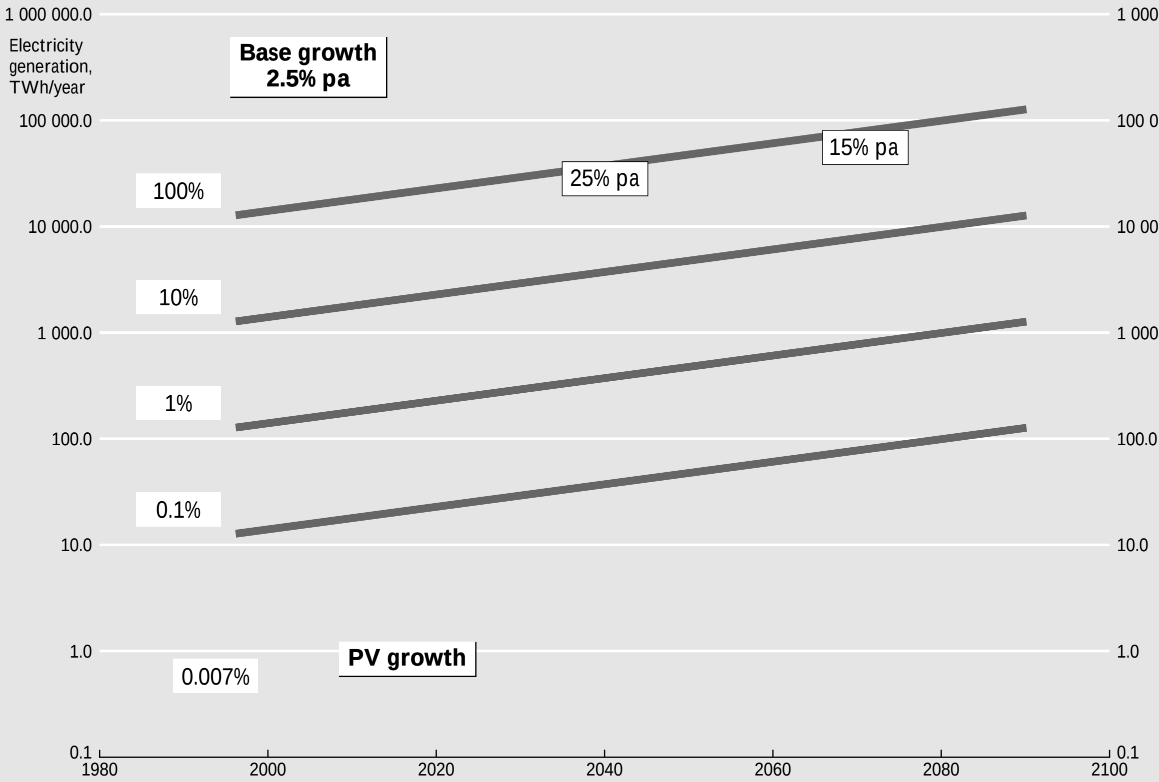
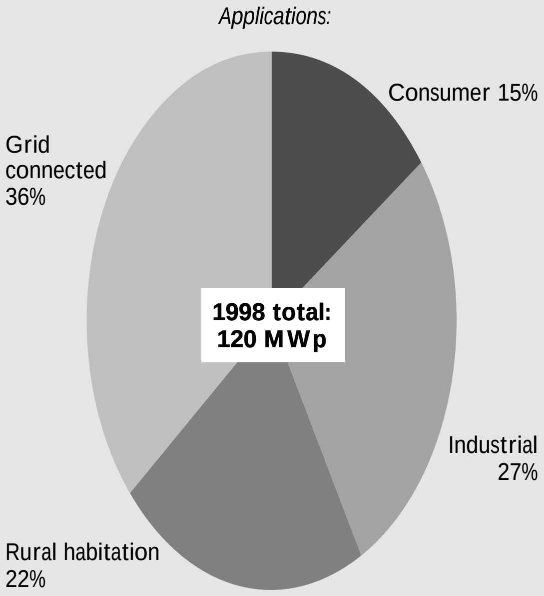


Figure 4. **Photovoltaic industry world market**



Source: Siemens Solar

Figure 5. **Comparison: thin film vs crystalline**

Lower consumption of direct and indirect materials

Independence from shortages of raw silicon

Fewer process steps (13 steps for thin film vs 25 for crystalline)

Process lends itself to automation

Figure 6. **Thin film structure**
(CIS – Copper Indium DiSelenide)

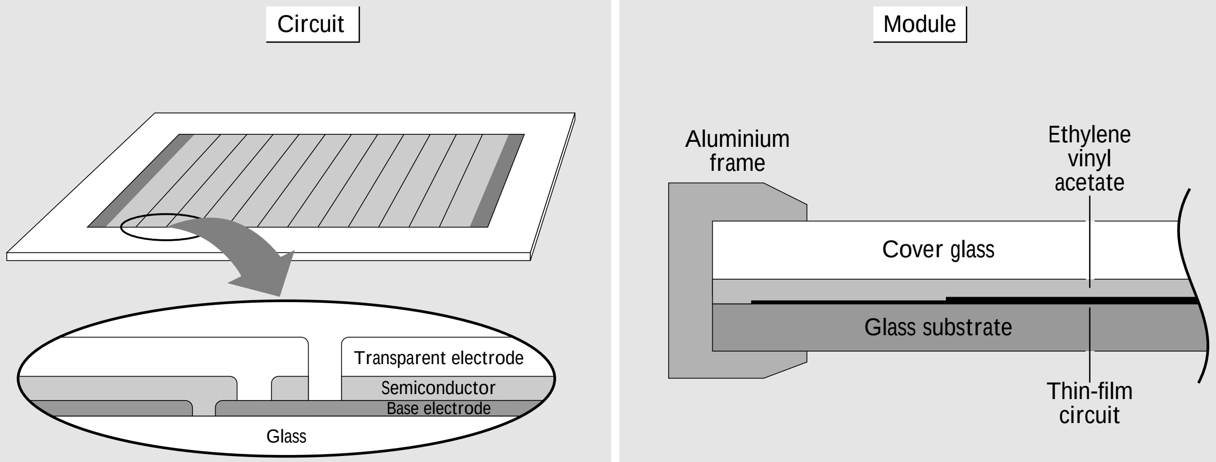


Figure 7. **Process comparison: crystalline vs thin film**

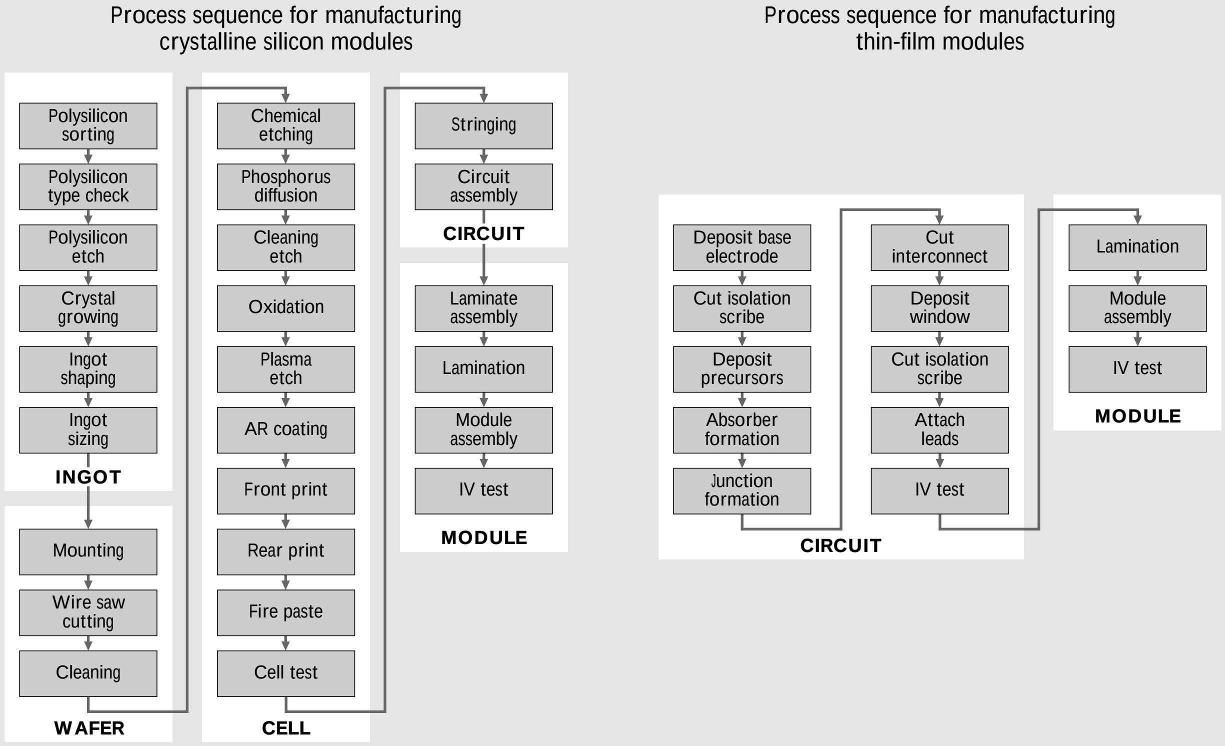


Figure 8. **Cost comparison: crystalline vs thin film**
(same production volume)

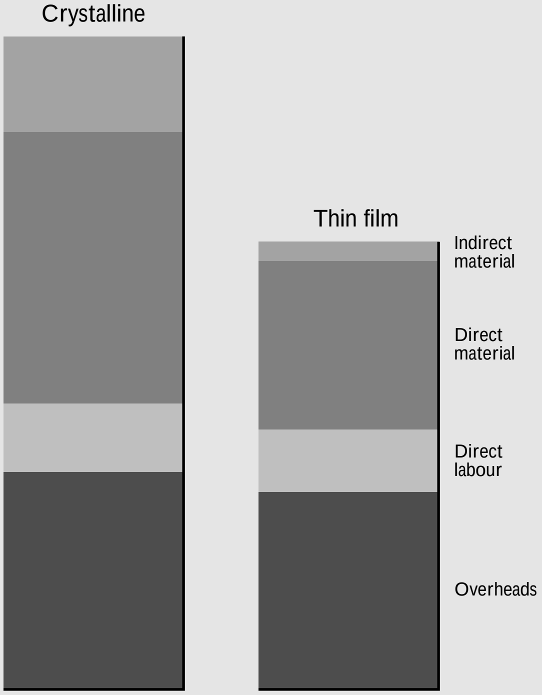


Figure 9. **CIS is the best thin-film approach**

All thin-film PV modules have similar manufacturing steps

All thin-film PV modules have similar area-related costs

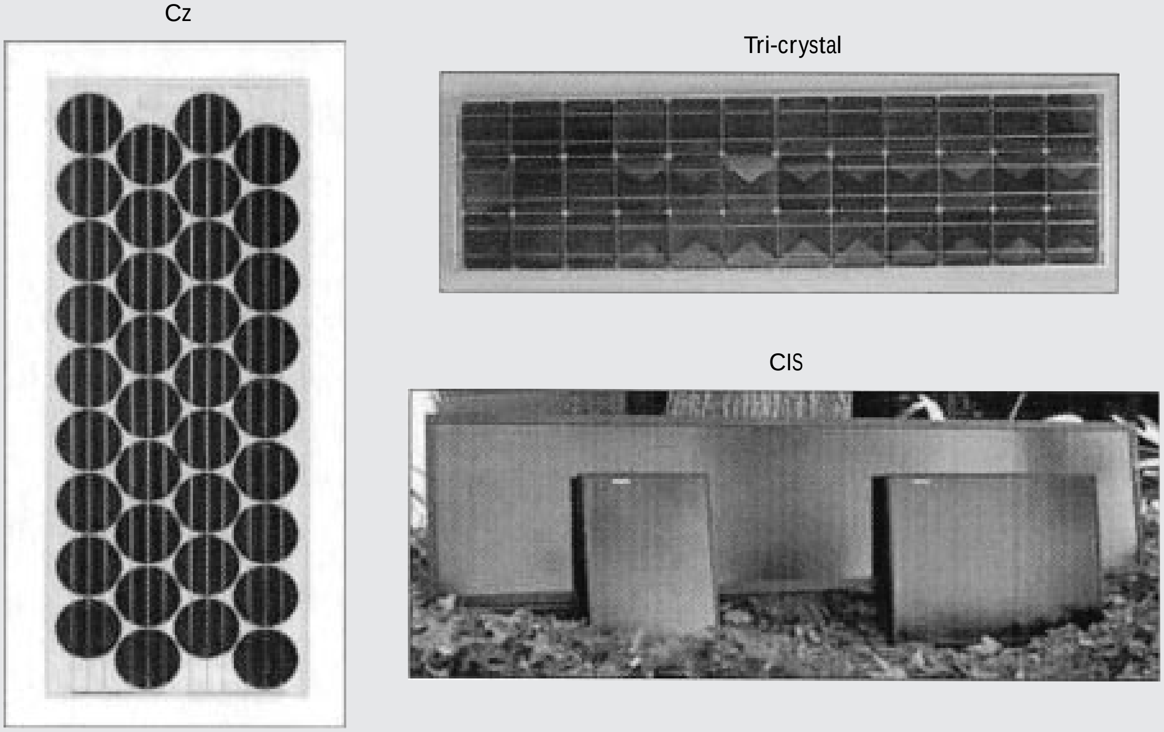
The higher efficiency CIS technology means more watts per square foot resulting in lower cost per watt

Difference between new technologies:

Technology	**Efficiency**
CIS	12%
CdTe	8%
A-Si	6%

Example: CIS 40W module is 4.5ft^2 and 14 lbs
A-Si 43W module is 8.9ft^2 and 33lbs

Figure 10. **Product technology path**


Cz

Tri-crystal

CIS

electricity grids, solar energy will have to become a lot less expensive. More than 90% of all solar cells are currently manufactured from wafers of extremely pure silicon. Manufacturing 1MWp requires around 15 tonnes of solar-silicon. This amount costs around US$ 400 000.

Use of thin-film technologies allows the thickness of the solar cells and thus the consumption of materials to be reduced by a factor of 100. At the same time, the number of manufacturing stages will be halved and automation made easier (Figure 5).

Figure 6 shows a schematic diagram of thin-film modules while Figure 7 shows a comparison of the processing steps for crystalline silicon and thin-film modules. The cost benefits of thin-film technology are largely on the use of materials side (Figure 8). The higher the efficiency of the technology used, the more evident these benefits are. This is why Siemens Solar has chosen CIS (Copper Indium DiSelenide) technology (Figure 9). With similar costs per unit of surface area, it produces the best performing modules compared with other technologies currently available.

Figure 10 compares solar modules of different designs. On the left is a monocrystalline module with cells made of silicon manufactured according to the Czrochalski (Cz) process. In the module shown at the top right of Figure 10, the cells have a three-crystal structure which allows the thickness of the cells to be halved. The bottom right picture shows samples of thin-film modules manufactured according to the CIS process. The CIS layer is less than 2µ thick.

The current learning curve for the photovoltaics industry has been calculated as 18%. This means that manufacturing costs have been reduced by 18% in each case when the accumulated production volume has doubled. The task of research and development is to maintain this rate over the long term if possible. If the market develops as expected, this would lead to a halving of costs around every eight to 10 years.

Energie pour un développement durable de l'Afrique

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L'énergie est le soubassement de toute activité économique. Or, lors de l'élaboration du Plan d'Action de Lagos pour le développement économique de l'Afrique 1980-2000, un constat s'est dégagé : la situation énergétique africaine, très préoccupante, est mise en évidence par les considérations suivantes, citons : « l'absence dans la plupart des pays d'une politique énergétique, de programmes directeurs de développement énergétique à court, moyen et long termes ; le manque d'intégration des activités énergétiques aux efforts nationaux globaux pour les plans de développement ; la nécessité de dresser un bilan exhaustif de toutes les ressources énergétiques, de leur potentialité, de leurs possibilités de développement et d'utilisation des besoins énergétiques, y compris les équipements adéquats ; la nécessité d'entreprendre des actions communes entre les pays africains pour le développement et l'utilisation des ressources existantes en Afrique. Ce qui pose comme préalable l'initiation et le développement d'une coopération énergétique aux niveaux sous-régional et régional ».

A un an de la fin de la période de mise en œuvre du Plan d'Action de Lagos, quelle est la situation énergétique de l'Afrique ? Quelles sont les actions entreprises en la matière pour un développement durable du continent ?

Ressources énergétiques de l'Afrique

Près de vingt ans après les objectifs exprimés dans le plan d'Action de Lagos la crise économique africaine ne s'est guère améliorée et la région entière est confrontée à de sérieux problèmes de détérioration des termes de l'échange aggravés par les fardeaux croissants du service de la dette. Les produits d'exportation qui constituent le pilier central de l'économie africaine connaissent une très sérieuse détérioration au niveau de leur cours sur le marché international.

Du fait du déséquilibre au niveau de l'utilisation des différents types d'énergie, une pression considérable est exercée sur l'environnement, avec de sérieuses implications sur l'écologie entière du continent. Les caractéristiques du secteur énergétique africain sont les suivantes : il existe une forte dépendance à l'égard des combustibles traditionnels tels que le bois de chauffe ; l'Afrique dépend également beaucoup du pétrole comme combustible commercial. Pour de nombreux pays, le pétrole constitue plus de 50 % de la facture des importations.

La situation de fourniture d'énergie dans les pays du continent n'est donc pas satisfaisante, alors que, paradoxalement, la région possède plus de la moitié des ressources énergétiques mondiales. A titre d'exemple :

Potentiel hydraulique

Il est estimé que l'Afrique possède plus de 35 % du potentiel hydraulique non exploité du monde (200.000 mW sur 565.000 mW). Le potentiel exploité concerne à peine 7 % du total disponible.

Charbon

Les ressources de charbon exploitable de la région africaine ont été estimées à environ 181 milliards de tonnes. Seule une petite portion de ce potentiel a été exploitée.

Hydrocarbures

Les estimations du potentiel pétrolier vont de 57 à 71 milliards de barils, celui du gaz est évalué à environ 190 milliards de m^3 de gaz naturel.

Bois de chauffe

Il est généralement admis que plus de 70 % des besoins énergétiques du continent sont satisfaits à partir du bois de chauffe. En raison du caractère non commercial de cette source d'énergie, il n'existe pas de statistiques fiables. Elle constitue cependant la principale source d'énergie primaire pour la majorité des zones rurales, particulièrement au sud du Sahara. Le bois de chauffe est utilisé pour la cuisine, le chauffage, l'éclairage, le séchage de produits agricoles, etc.

Les sources d'énergies renouvelables (ER)

Elles sont très importantes. La durée d'ensoleillement varie de 3000 à 4000 heures par an. L'intensité du rayonnement reçu au sol se situe en moyenne entre 4 à 6 kW/m^2/j. Le gisement éolien permet l'exploitation dans nombre de pays d'éoliennes, voire d'aérogénérateurs. Conscients que l'exploitation des ces ressources renouvelables peut contribuer à l'amélioration de la qualité de vie de leurs populations à majorité rurales, les Etats africains, au lendemain de la Conférence des Nations Unies sur les Sources d'énergies nouvelles et renouvelables, tenue à Nairobi en 1981, ont engagé la réalisation de projets et programmes en la matière. De plus, l'exploitation de ces sources d'énergie a très peu, voire n'a pas du tout, d'effet négatif sur l'environnement ; or, il n'y a pas de développement durable sans préservation des écosystèmes. Aussi, l'essentiel de la présente contribution à cette Conférence portera sur les efforts déployés par les Etats africains dans le cadre de l'exécution du Plan d'Action de Lagos en ce qui concerne l'exploitation des ressources en ER pour la satisfaction de leurs besoins fondamentaux de développement.

Programme énergétique africain

A partir de la situation énergétique du continent africain brièvement décrite ci-dessus, et surtout sur la base des recommandations contenues dans le Plan d'Action de Lagos, la Banque africaine de développement (BAD) a entrepris une série d'études à partir de 1990 ; ces études ont consisté à : mettre à jour un inventaire de chaque ressource d'énergie ; élaborer des projets prioritaires, en déterminer leur faisabilité entière.

Ces projets auront un caractère multinational avec des composantes d'intégration, un caractère national mais avec des retombées multinationales. Ces projets prioritaires ainsi qu'une Charte africaine de l'énergie à élaborer constitueront le Programme énergétique africain. Selon le calendrier établi initialement, ces études devraient être achevées en 1994. Mais ce Programme n'est pas encore disponible au niveau des Etats.

Promotion des énergies renouvelables pour un développement durable

Comme nous l'avons indiqué précédemment, une Conférence des Nations Unies sur les Sources d'énergies nouvelles et renouvelables s'est tenue à Nairobi en août 1981.

Devant l'accroissement important de la population mondiale et de l'expansion de l'industrialisation, les nations se préoccupent de la disponibilité de l'énergie en quantité suffisante pour satisfaire la demande toujours croissante. Les réserves en ressources d'énergie classiques (hydrocarbures notamment) étant limitées, il est urgent de mettre en valeur les ressources renouvelables que sont le soleil, le vent, la biomasse, etc.

L'objectif visé par la tenue de cette Conférence était donc d'examiner les voies et moyens d'exploiter ces sources alternatives. D'importantes mesures furent adoptées et les Etats invités à les mettre en œuvre.

Evaluation du gisement énergies renouvelables

Les Centres Nationaux de Recherche-Développement (R&D) existant déjà ont vu leurs moyens accrus pour entreprendre ce travail ; de nouveaux Centres ont été créés. Les stations météorologiques nationales ont été mises à contribution. Les gisements ER, nous l'avons vu, sont importants.

Recherche-Développement et Formation

Afin de pouvoir « domestiquer » ces ressources, les Etats, pour renforcer les Centres Nationaux, décident de la création de structures régionales. La Communauté Economique de l'Afrique de l'Ouest (CEAO) créa le Centre Régional d'Energie Solaire (CRES) en 1978 et l'Organisation de l'Unité africaine (OUA), le Centre Africain d'Energie Solaire (CRAES) quelques années plus tard. Si le Centre de l'OUA n'a jamais fonctionné, celui de la CEAO par contre a été construit et a fonctionné jusqu'à la liquidation de la Communauté économique en 1992. Les résultats obtenus par les Centres Nationaux et le CRES sont appréciables.

Au niveau de la R&D, des appareils fonctionnant grâce à l'énergie solaire ont été mis au point, notamment des chauffe-eau et des distillateurs solaires, des séchoirs, des pompes solaires thermodynamiques. Certains, comme les chauffe-eau, ont même donné lieu à l'implantation d'usines de productions telles que la SINAES à Dakar au Sénégal et l'ONERSOL au Niger vers la fin des années 1970 pour ne citer que ces exemples.

Au niveau de la formation des spécialistes, avec l'appui de la communauté internationale, notamment de l'UNESCO, l'Afrique dispose aujourd'hui de chercheurs, ingénieurs et techniciens, capables de mener à bien aussi bien des programmes de R&D que des programmes d'équipements (installation, suivi et évaluation) en la matière.

Projets et programmes solaires africains

Sous le vocable « énergie solaire », il faut entendre énergie renouvelable. La maîtrise des technologies d'utilisation de ces sources, leur intégration progressive à une échelle significative dans les programmes sectoriels de développement doivent permettre d'apporter des réponses originales à la problématique énergétique des pays et contribuer ainsi à un développement plus large et plus équilibré, en particulier dans le monde rural.

Cette préoccupation a été une constante pour nombre de pays africains depuis leur indépendance. C'est dans cette optique que les premiers Centres Nationaux évoqués plus haut ont vu le jour en Afrique de l'Ouest dès les années 1960 et le CRES en 1978.

Le programme du CRES

Comme nous l'avons indiqué, le CRES a fermé ses portes avec la liquidation de la CEAO, mais certains programmes réalisés et en cours de réalisation dans onze pays d'Afrique de l'Ouest ont été initiés par le CRES. Ces pays sont les pays membres du Comité Inter-Etat de Lutte Contre la Sécheresse au Sahel (CILSS) ; le CRES est devenu commun à la CEAO et au CILSS en 1982. En particulier, le CRES a aidé les Etats membres à élaborer, de 1983 à 1986 leurs programmes nationaux d'équipements en ER. La synthèse de ces programmes nationaux a donné naissance à un Programme Régional d'Equipement.

Aujourd'hui le Programme Régional Solaire du CILSS financé par l'Union européenne, et qui va entamer sa troisième phase de réalisation, est largement inspiré du Programme Régional du CRES. Mais quel est donc ce Programme Régional du CRES ? Les pays concernés ont une situation énergétique parmi les plus préoccupantes d'Afrique : une dépendance à l'égard de l'extérieur qui conduit, dans tous les pays, à un déficit croissant de la balance commerciale, et ce, malgré une consommation d'énergie commerciale moderne extrêmement faible : 70kg d'équivalent pétrole ; un déséquilibre grave entre les centres urbains, où se concentre l'essentiel du service énergétique, et les zones rurales ; des réponses imparfaites des énergies conventionnelles aux besoins décentralisés de populations rurales réparties sur des territoires très étendus, où l'approvisionnement en carburant est très difficile et onéreux ; un rôle prépondérant dans le secteur domestique du bois de chauffe, qui représente en moyenne 80 à 90 % de la consommation énergétique totale, et qui est exploité, transformé et utilisé dans des conditions souvent peu rationnelles ; une pression permanente sur le capital forestier, qui contribue à l'accroissement des déséquilibres écologiques et engendre de plus en plus de difficultés pour l'approvisionnement des populations en bois et en charbon de bois.

Les Etats de la sous-région ont ainsi pris conscience du rôle essentiel de l'énergie dans leurs stratégies de développement, des impasses auxquelles pourrait mener l'utilisation non rationnelle des seules énergies classiques, et de la nécessité de diversifier les sources d'énergies en faisant notamment appel aux ER. Le Programme Régional du CRES a été élaboré suivant la démarche indiquée ci-après.

Le programme régional d'équipement du CRES

Grands programmes

- hydraulique : exhaure de l'eau, gros villages et centres secondaires ;
- santé rurale : équipement de dispensaires ;
- éducation et culture : éclairage de classes, télévision scolaire ;
- télécommunication : alimentation faisceau hertzien – téléphonie rurale ;
- foyers améliorés : en milieux rural et urbain ;
- transport : signalisation ferroviaire et aérienne.

Programmes moteurs

- information : réémetteurs radio, TV communautaire ;
- défense : radiocommunications ;
- intérieur : radiocommunications pour l'administration ;
- tourisme : éclairage campement, radio communications ;
- élevage : exhaure de l'eau, éclairage postes de santé froide vaccins ;
- météo : radiocommunications ;

- carbonisation du bois ;
- conservation des aliments.

Autres programmes

- électrification rurale : micro-centrales hydrauliques, petites centrales photovoltaïques ;
- habitat et bâtiments publics : chauffe-eau solaire, climatisation ;
- agro-industries : production d'électricité par gazogènes et d'alcool carburant.

Le Programme Régional Solaire du CILSS qui est en cours de réalisation depuis bientôt dix ans a pris essentiellement en compte l'hydraulique villageoise et pastorale ainsi que la santé rurale. En ce qui concerne les autres aspects du Programme CRES, certains Etats les ont pris en compte dans leurs Programmes Nationaux. Le Programme du CILSS s'est par exemple limité aux équipements photovoltaïques alors que dans certains projets nationaux, il porte sur l'énergie solaire thermique, l'énergie éolienne, la biomasse…

Programme solaire africain, composante du PSM

L'Afrique a abrité en 1996 à Hararé (Zimbabwe) le Sommet Solaire Mondial sous l'égide de l'UNESCO. Comme les autres nations du monde, elle a approuvé le Programme Solaire Mondial 1996-2005. Cinq Etats africains sont membres de la Commission Solaire Mondiale mise en place pour le pilotage du Programme. De nombreux Projets de Haute Priorité ont été élaborés par les Etats et soumis à l'UNESCO. A titre d'exemple, présentons un de ces projets :

Villages Intégrés Solaires (VIS)

Un projet pilote de Village Intégré Solaire a été réalisé au Niger en 1991. Un VIS est un village qui répond à un certain nombre de critères. Il doit avoir une population dynamique de 2000 à 5000 habitants. Eloigné du réseau électrique, il doit disposer d'un minimum d'infrastructures : un ou plusieurs forages ou puits, un dispensaire ou centre de santé intégré, une école, un centre d'animation culturelle. L'objectif global visé est l'approvisionnement en eau potable, l'amélioration des conditions de santé et d'éducation des populations. Plus spécifiquement, par les installations de pompes solaires photovoltaïques, fournir de l'eau potable en quantité en allégeant la corvée des femmes ; la réfrigération et l'éclairage photovoltaïques améliorent les conditions de travail et de séjour dans les centres de santé. Les écoles et les lieux d'animations culturelles éclairés la nuit grâce à l'énergie solaire voient la qualité des prestations améliorée. La mise à disposition de chauffe-eau solaire à la maternité du centre de santé permet d'économiser le bois de chauffe déjà si rare.

Le Projet de Haute Priorité VIS préparé par la République du Niger dans le cadre du Programme Solaire Mondial concerne 365 villages pour un coût total d'environ 30 millions $US.

Conditions de réussite de ces projets et programmes

Malgré la volonté politique exprimée au niveau sous-régional de prise en compte des ER pour la résolution des problèmes énergétiques, les actions concrètes entreprises en vue de l'atteinte de cet objectif n'ont pas encore permis de déboucher sur une synergie des efforts de tous les acteurs nationaux du secteur de l'énergie. Il subsiste encore des contraintes parmi lesquelles :

- Les contraintes d'ordre institutionnel et réglementaire : manque de collaboration entre les différents acteurs ; absence de « joint venture » pour la production de certains équipements ; manque ou insuffisance de mesures incitatives (textes réglementaires, mesures fiscales) ; peu ou pas d'implication des compagnies d'électricité dans le secteur des ER ; insuffisance de mesures tendant au renforcement de capacité (ressources financières et humaines) des structures de recherche ; manque de réglementations en la matière.
- Les contraintes économiques et financières : coûts élevés des installations ; absence de crédits à l'importation ; la non-implication des institutions financières nationales ; le faible pouvoir d'achat des utilisateurs ; la faiblesse de l'implication des opérateurs privés ; l'insuffisance des moyens financiers mis à la disposition des centres de recherche.
- Les contraintes liées à l'information : insuffisance de l'information des décideurs se traduisant par un faible engagement politique; manque d'informations des utilisateurs.
- Contraintes liées à la formation : non prise en compte des ER dans les programmes de formation scolaires ; insuffisance de l'expertise nécessaire à la production et à la maintenance des installations ; insuffisance de l'animation scientifique dans les centres de recherche ; insuffisance de la formation des chercheurs ; faiblesse voire inexistence du budget de formation ; insuffisance de la formation des utilisateurs à la maintenance et à la gestion des installations.
- Les contraintes socioculturelles : le poids des préjugés et des coutumes ; mauvais dimensionnement ; faible contrôle de qualité des équipements; insuffisance de responsabilisation des bénéficiaires pour la gestion des équipements; manque d'implication des populations dans l'élaboration des projets; insécurité des installations.

- Les contraintes d'ordre technique: manque de stratégie de maintenance et de suivi/évaluation; manque de pièces détachées ; insuffisance de l'évaluation du potentiel/ gisement.

Conclusion

Les conditions de réussite des programmes et projets ci-dessus énumérées ont été unanimement admises par l'ensemble des experts des quatre pays Ouest africains réunis à Niamey du 15 au 19 mars 1999. Mais, à la lumière des résultats du dernier Forum de la Commission Solaire Mondiale, tenu à Hararé du 29 au 31 mars 1999, pour un bon nombre de pays africains le Programme Solaire Mondial (PSM) connaît un début d'exécution. De son côté, l'Union Economique et Monétaire (UEMOA) ainsi que la Banque Africaine de Développement, envisagent la relance des activités du CRES.

On peut donc espérer que les 66 % de la population africaine qui vivent en milieu rural verront leur condition de vie améliorée au cours de la première décennie du troisième millénaire par l'utilisation massive des ER.

The contribution of S&T development to sustainable energy in developing countries with a case study on Indonesia

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Science and technology is a manifestation of human creativity and as such is an integral part of people and civilization. However, in its implementation and translation into budgets and human resources development, a wide spectrum of discrepancies still prevail in many countries. On the other hand, many developing countries have pressing needs in meeting the energy demand for the quality of life and prosperity of their peoples, as well as developing appropriate economic infrastructure. In addition, locally available non-renewable energy resources are rapidly being depleted while a global environmental requirement has imposed a progressive and profound challenge. The need for the utilization of renewable and sustainable energy, and for the development and utilization of efficient energy technologies has come to the fore.

With the progress of science and technology and the understanding of humankind of the role of science and technology, the search for new, renewable and efficient energy has progressed at a very impressive pace. The developing countries are challenged to establish an appropriate strategy to meet their energy and economic objectives and to establish synergistic development and utilization of science and technology, as well as to participate in the global effort to promote the application of sustainable energy.

Energy, GNP and human resources

The relation between the prosperity of a country, as indicated by its gross national product (GNP), and energy consumption is well known. Total energy use per capita might be related to productivity per capita as measured by GNP for many countries of the world. There is also some indication that the developed countries are high users of energy per capita while the developing nations are low users per capita, although the developed countries make better use of their energy resources by producing more of the world's goods and services per capita. Figure 1 shows energy use per dollar of GNP in relation to GNP per capita for various countries; the energy consumption of some of the developed and developing countries is shown in Figure 2. The differences shown are related to the human resources of these countries.

The ability of people to think systematically, in depth and long term produces science. Science gives birth to technology, i.e. science-based ways of producing goods and services. People make use of technology to improve value-adding processes, i.e. processes for transforming raw materials and intermediate goods into finished products of greater value. In turn, these value-adding processes themselves are continual, complex processes and are successful if the use of machinery, the skill of people and the material can be fully integrated by technology to produce goods and services of greater value than the raw material and other inputs. Some relationship exists between the level of development of technology due to the standard of living and the standard of living generated by levels of development in technology. There exists some relationship between the standard of living and the number of experts in some selected countries, and

Figure 1. **Energy, GNP and human resources**

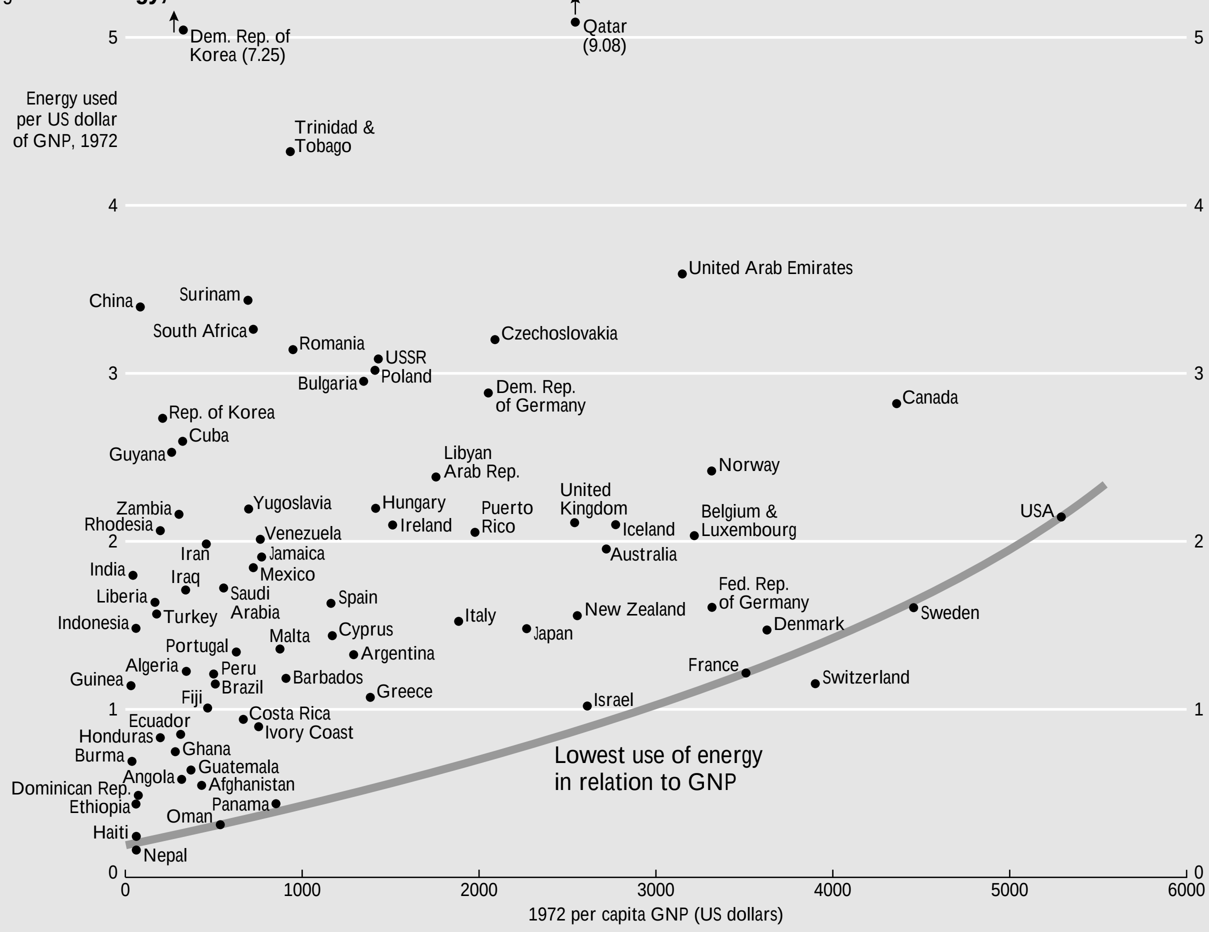
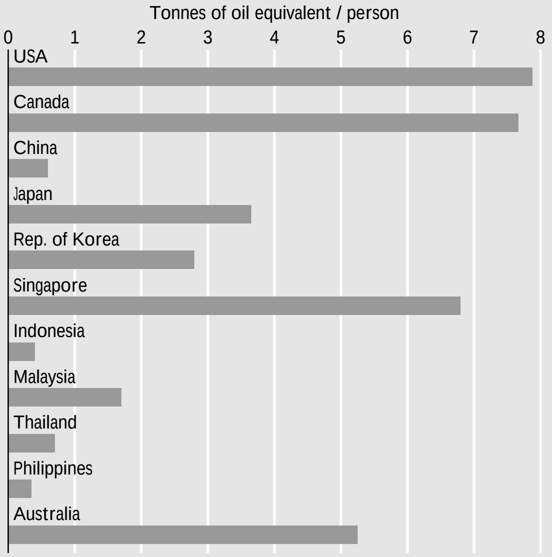


Figure 2. **Primary energy consumption per GDP**



there is a direct relationship between the important role of experts and scientists in developing the technology, the efficiency of energy consumption and the possibility of seeking new alternative energy.

Globally, there is a growing awareness and concern regarding general environmental issues and a growing appreciation of the links between economic activity, economic growth and the environment. Increasingly, a shift towards sustainable development is seen to present opportunities, as well as challenges. Environmental challenges can provide incentives for the development of new environmental technologies.

Technology development and management of change in Indonesia; synergistic development of S&T infrastructure

For the past 30 years, Indonesia has undertaken a national development plan that has already transformed it from a less-developed country to a transitional one by following a systematic development strategy, with long-term objectives of achieving an affluent and just society by transformation from an agricultural to an industrial economy supported by a strong agricultural base, giving priority to the development of human resources and the acquisition, application, mastery and development of science and technology. History has shown that science and technology does not only contribute to the socio-economic development of a country, but also constitutes a determining factor of it and of the establishment of its economic resilience, speeding up economic development and enhancing the prosperity of the people. The mastery of science and technology is not only essential for a country to grow but, more significantly, for it to establish and enhance its capacity to grow. An appropriate strategy has to be introduced to effectively acquire national technology capabilities that not only support the effort to achieve such a goal, but also accelerate its achievement in the shortest possible time-frame while bringing the society synergistically to a modern quality of life. Such effort is required with the profound wave of economic, technology and information globalization that has been taking place on the threshold of the third millennium, characterized by the information society and knowledge-based economy.

To develop industrial infrastructure that is supported by significant domestic market demand, the strategy for industrial transformation in four stages, which ‘starts with the end and ends with the beginning’, is formulated, utilizing nine vehicles for its development. Aircraft technology is one that may serve as a spearhead both in technology acquisition and in establishing national confidence and resilience. The strategy is essentially aimed at achieving the dual objectives of enhancing human resources potential and the mastery of science and technology, and has been formulated in four stages, i.e.:

- technology acquisition through the transfer of existing technology to achieve a value-adding process, capitalizing on the acquisition of a manufacturing capability of advanced technology products already on the market;
- integration of acquired and existing technology into the design and production of completely new products to be introduced onto the domestic and international markets;
- integration of existing and new technology into the design and production of completely new products to be introduced onto the domestic and international markets;
- acquisition of a large-scale basic research capability and the implementation of basic research as key elements in developing competitive generic technologies.

The strategy was realized on the basis of the market imperative, initiated in the aircraft industry and followed by other high and economically strategic technologies, taking into consideration various relevant economic, social and cultural factors.

The application of the strategy for industrial transformation has resulted in the conception, design, production and certification of the CN-235 aircraft, which received FAA certification in 1986. The aircraft has been utilized extensively for domestic flights serving numerous routes in Indonesia. In addition to entering into service in Indonesia in 1986, some CN-235 aircraft have been delivered to ASEAN countries and also to Venezuela. The development of N-250 50-70 passenger commuter aircraft was started in 1987 in the technology development phase of the industrial transformation scheme to address the domestic and global market potential in the 1990-2015 time-frame. The implementation of the industrial transformation strategy can be viewed as a synergistic effort in the utilization and development of various strategic elements for economic development.

To translate macro-economic considerations into micro-economic, technological and engineering aspects associated with the industrial transformation strategy, in 1978 Badan Pengkajian dan Penerapan Teknologi (BPPT, the Agency for the Assessment and Application of Technology) was established. Based on the successful progress in implementing the industrial transformation strategy, the Agency for the Strategic Industries was created in 1989, incorporating 10 state-owned companies, including IPTN. These companies represent the nine vehicles for industrial transformation and serve as a spearhead for establishing industrial excellence. The Centre for Research, Science and Technology (PUSPIPTEK), which houses and promotes the development of research laboratories essential for national development belonging to the non-departmental research institutions, was also established in 1978. These institutions are the Atomic Energy Agency (BATAN), the Indonesian Institute of Science (LIPI), BPPT and at later stages the Indonesian Institute for National Aeronautics and Space (LAPAN). With the establishment of the technology infrastructure within the framework of in-country technology development, the country has been able to respond positively to local as well as global signals of change. Such a challenge demands synergistic networking between industry, research and educational institutions, as well as government agencies as facilitators, to establish reliable national industrial capabilities and to enhance production competitiveness. The partnerships between private enterprise, the productive sector, science and technology-oriented institutions and government should be enhanced and established at grass-roots levels. The role of small and medium-sized enterprises is enhanced through industrial partnership incentives and financing as well as other empowerment policies.

Enhancing the role of S&T for sustainable energy development in Indonesia

Increased energy demand, in particular in the form of electricity, due to development activities as well as to meet the needs of the rural population, calls for a new energy strategy to establish a just and prosperous society entering the third millennium in a global environment that is oriented towards a knowledge-based economy and sustainable environment. The energy policy to promote intensification, conservation and diversification of energy resources has been adopted since the early 1970s. Oil, which was instrumental in financing development efforts, has been progressively substituted by non-fossil fuel exports. The depletion of fossil fuel reserves and the increasing concern for the environment and sustainable development imperative has prompted a new operational policy. In the utilization of energy resources, non-renewable as well as renewable ones, an energy cost structure, which incorporates environmental conservation efforts as inseparable parts of energy resources, has been considered. The utilization of fossil fuel resources is reviewed to allow consideration of a pricing policy that addresses environmental as well as socio-economic concerns. There will be a balanced natural gas policy that is directed towards its domestic use for electricity and feed stock, to allow the value-adding process and conducive investment opportunities and human resources development. The utilization of energy resources should be accompanied by the development and utilization of energy-efficient technologies.

In addition, the utilization of energy in a balanced and sustainable structure, combining renewable and non-renewable energy resources should be promoted.

The provision of electricity for rural areas in a decentralized or individual system approach has been considered. Since it is not economically feasible to establish conventional electric grids in remote areas, the application of a photovoltaic system, in particular the Solar Home System for rural electricity, has been initiated. The modest (50Wp per household) electricity provided through the Solar Home System Photovoltaic Rural Electrification programme can meet every household's needs for lighting, information and communication (black-and-white television and/or radio). Such performance is essential in developing the potential capabilities of human resources and the quality of life in the rural and remote areas. From the point of view of diversification of energy, environmental and practical considerations, it is economically feasible for remote areas. Therefore, the One Million Rural Solar Homes System (SHS) Project was officially launched in June 1997 with the ultimate goal of providing electricity to 1 million households, about 10% of the estimated 10 million rural families without electricity, within 10 years. The programme uses a revolving fund scheme as a model for the installation of the first 32 000 units of SHS in Eastern Indonesia, and the first phase was completed in July 1998.

Various countries and funding agencies provide loans for PV Solar Home and related systems. The World Bank loan and Global Environmental Facility (GEF) grant will be used to provide funds for distributors of these types of systems to supply some 200 000 units to the Indonesian market. This pragmatic renewable energy development and application approach is in line with the strategy and recommendations of the Harare Declaration on Solar Energy and Sustainable Development in 1996. Another significant part of this programme is the integrated scheme for local manufacturing and technology development of hardware with the involvement of the private sector. Elements of technology development, including various stages of research, in the field of solar energy have also taken place in Indonesia.

A strategy for enhancing the role of S&T for sustainable energy development

A strategy based on the experience gained in the technology and industrial development of photovoltaic electricity for rural application can be followed for other new and renewable energy programmes. First, based on an in-depth feasibility study, a pilot project is being initiated incorporating relevant parties from the community, industry, financing institutions and the governmental research and technology application institutions. The pilot project will serve as a tool for further assessment of such applications, including assessment of national capabilities and societal demand and acceptance, as well as promotion of the practical and economic applications of the technology. The pilot project can be developed to establish confidence in the technology and mobilize local industries, as well as participation by foreign industries, and serves as a tool for overall assessment of the feasibility of the product, penetration into the market and technology development. Through such studies a wider programme can be introduced to address the needs of the larger national market. At the same time national capacity-building can be fostered through human resources development, technology support for product selection and certification and enhancement of local industrial capabilities.

Next, based on favourable results of the pilot project, through the leadership and vision of governmental research and technology application institutions, a national programme can be formulated and established. A concerted effort has to be carried out to obtain the initial financial support, as well as to invite the interest and participation of relevant private sectors and funding agencies. By addressing an economically feasible application approach and formulating national priorities, the programme could open up wider market opportunities for the private sector. An integrated scheme for local manufacturing and technology development of hardware and the involvement of the private sector should be introduced. Financial assistance and fiscal incentives for market penetration should be introduced, associated with a small and medium-sized private enterprise empowerment policy. The establishment of such a programme will promote and progressively generate the domestic market. Technology and business partnerships between foreign and local industries can be promoted which will not only address the national market but also look at the foreign market as well. Research institutions, universities and local industries may cooperate and establish networking to boost the local industry capabilities. The research effort may be boosted due to growing industrial needs for competitiveness.

The establishment of a national programme to promote the provision of electrical energy through renewable means may provide opportunities for cooperative units and for the private sector to produce and sell electricity. Other renewable energy promotional efforts could follow the above-mentioned strategy, including wind energy application for rural areas in eastern Indonesia and the Grid Interconnected Photovoltaic Electricity System for high- and medium-income housing. The objectives of the Grid Interconnected Photovoltaic Electricity System for urban and sub-urban communities are to explore, promote and assess the commercialization and the general feasibility of the photovoltaic grid-connected system. The strategy can speed up the contribution of science and technology to local technology and local industry development, while addressing the needs of rural people for sustainable energy.

Concluding remarks: contribution of S&T to the promotion of renewable energy development

A new strategy associated with energy, natural and human resources has evolved in addressing the profound global concern for a sustainable effort to improve the quality of life of mankind by promoting increased utilization of renewable and sustainable energy, as well as enhancing energy efficiency and efficient energy technologies. A novel and sustainable energy development strategy is being formulated to meet the increasing energy demand for domestic needs as well as to earn foreign exchange required for development. The systematic, consistent and synergistic application of the industrial transformation strategy for scientific, technological and industrial development in Indonesia, spearheaded by the aerospace industry, has resulted in a multitude of gratifying achievements and given further confidence in the strategy.

Several economically strategic industries have grown into significant manufacturers. A significant number of skilled technical manpower, including professional engineers and young and dynamic PhD holders, has been produced and is actively contributing to the industrial and economic development of the country. Research and technology application institutions such as LAPAN, BPPT and LIPI have been instrumental in developing scientific and technological infrastructure required in certain areas, such as in the field of space-based natural resources monitoring technology, renewable energy technology and a maritime development programme. The synergistic application of the industrial transformation strategy has a significant impact on the development of human resources, scientific and technological capability, and on the economic progress of the nation. Renewable energy initiatives have been developed with a significant thrust through the establishment of national programmes that address the needs of rural communities and are directed towards harnessing new and renewable energy technologies, supported by the establishment of local technological capabilities. As a significant part of this strategy, an integrated scheme for local manufacturing and technology development of hardware and the involvement of the private sector has taken place, such as in the Solar Home System programme, contributing to the value-adding process for economic and technology development as well as a better quality of life.

Thematic meeting report

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The present thematic meeting was attended by over 30 of the participants attending the World Conference on Science from all the major geographical areas of the world. The participants brought to bear on the meeting their experience and points of view on different aspects of the energy sector. The subject of Energy Security in the Third Millennium had been debated by the UNESCO International School of Science for Peace during a Forum organized in cooperation with the Centro Volta and the Landau Network at Villa Olmo, Como, Italy, on 14-16 May 1998. The conclusions[1] of this meeting associated with the World Conference on Science were made available to the participants in the present meeting.

There was no doubt among the participants that the availability of the services provided by energy was an essential factor in the development process. However, the ways in which energy was produced and consumed would have to change very radically in the coming decades if the expected development was to be supported and if, at the same time, the environment was to be protected and sustainability ensured.

There was also consensus on the fact that fossil fuel reserves were still far from physical exhaustion. New findings and new technologies to exploit known reserves or to utilize ‘difficult’ products could greatly extend the period over which these sources would constitute the main basis of energy production.

However, demand for fossil fuels was expected to grow rapidly in the future unless appropriate measures were taken, as a consequence of population growth, expected economic growth and of the close link between economic development and energy consumption in the traditional energy systems. A fast growth in demand would lead to new tensions in the market, with a possible volatility of prices, shocks on the economy and political repercussions.

Two billion people on Earth, it was recalled, still did not have access to modern energy services such as electricity, natural gas or liquefied petroleum gas (LPG); most of them lived in rural areas and some represented the poorest strata of the population. Their state of deprivation was also the main driving force behind accelerated urbanization, which was creating dramatic new problems especially in the rapidly growing megacities of the Third World. Reducing poverty was one of the main challenges of the next century; the availability of energy services, although certainly insufficient alone to solve the problems, was a necessary prerequisite.

Science and technology have a great role to play in helping to solve this problem. They can develop new energy sources, new energy systems, more efficient ways of utilizing energy and of protecting the environment. They can broaden the range of options available to policy-makers at all levels and to individual citizens, allowing choices to be made and allowing the market to work. Opening up more options will facilitate the necessary energy transition, which is bound to have enormous dimensions.

Unfortunately, investments in energy research and development have been declining in the last few years in nearly all countries and in both the public and private sectors. This is due to a number of factors: the decreasing preoccupation with the availability and price of energy; shrinking government budgets; and deregulation of the energy sector, which has made short-term competition more stringent. As a consequence, medium- and long-term programmes have been particularly affected, just when it is the medium and long term that presents the most important challenges and the most difficult problems.

The participants unanimously recommended that this trend be reversed in future. It is not a question of indiscriminately supporting all energy-related research; indeed, public funding should be selective and focused, based on comprehensive, systems-wise, multidisciplinary assessment of the various technology options. Some examples of exceptions to the general decreasing trend within the private sector have been reported, in particular with regard to solar photovoltaic technology, where important investments also covering research and development aspects have been announced both by electronic industries and by major petroleum companies.

International cooperation may greatly enhance the effectiveness of research by exploiting synergy, by avoiding unnecessary duplication and by enhancing technology spillover. Although the possibility of applying the results of research in fields different from the one initially targeted cannot be the major justification for a research programme at its inception, the observation that this frequently happens is a further encouragement for the support of research with an advanced technology connotation.

Developing countries often have difficulties in judging which energy technologies or energy systems are best suited to their needs. Outside advice, especially from industrialized countries, is not always disinterested and, even when it is, it hardly takes into account all the peculiarities of the situation in the specific country or local area. Specific international or bilateral cooperation should address capacity-building in developing countries, in order to enable them to carry out independently the technology assessments needed to identify the energy trajectories most adapted to their specific conditions.

The relevance of research and development in specific energy technology fields was discussed in the meeting. Participants agreed that major emphasis should be placed on the area of renewable sources of energy. Wind energy, solar energy and especially energy from biomass could greatly contribute both to meeting scattered demand in rural areas and also to supplying part of power, heat and transport fuel in urban areas and industries. The innovation potential of at least some of these technologies was large and research could contribute to reducing their cost in the future. Improved efficiency in the final uses of energy and in energy conversion was another area of major concern, although results obtained in this area depended less critically on the outcome of research and development. New solutions for energy transmission and storage were mentioned as further points deserving great attention. Distributed, grid-connected generation of electricity was a sector of increasing importance that complemented both the traditional solution of large-scale power plants and supply to isolated users; microturbines, fuel cells and various types of renewable energy technologies could contribute to this new development.

Basic scientific disciplines underpinned all the energy-related research and development that was mentioned: among them, there was a need for specific improvements in fields such as materials science, electrochemistry, heat and mass transfer, biotechnology and advanced information technology.

Nuclear energy from fission is going through a difficult period: new plants are hardly competitive with fossil fuel-generating plants; the large size of such plants and the high up-front investment are a disadvantage in the present financial environment; preoccupations are still present among the general public as concerns safety, the final destiny of long-lived nuclear waste and the possible effects on the proliferation of weapons of mass destruction of a spread of nuclear technologies. However, many innovative approaches are possible, some of which (such as the accelerator-driven energy amplifier) would greatly reduce the preoccupations mentioned above. It seems useful to keep these options open for the future by continual research in these areas (although probably on a smaller scale than in the past).

Nuclear fusion is making relevant progress, but its practical application does not appear today any closer than it was 10 or 20 years ago. This is, however, a field in which international cooperation has played an outstanding role, with a programme which is well coordinated at the global level. Its value not only for long-term practical applications but also for challenging scientific problems justifies, in the opinion of most (even if not all) scientists, a continuation of the programme on the present basis.

It was recommended that the United Nations system devote continued attention to energy technologies, their development and transfer to developing countries, their interaction with economic and social development, and their relevance to the protection of the local and global environments. While, for nuclear energy, a specialized agency exists (the International Atomic Energy Agency in Vienna, Austria), this is not the case for other forms of energy, particularly renewable energy sources and technologies for the rational use of energy. However, the activities of various agencies of the United Nations system in this regard have been important and successful. One outstanding example is the World Solar Programme initiated by UNESCO, which has attracted the attention of many countries around the world, including their top representatives. Many other agencies, such as the United Nations Development Programme (UNDP) (also through the Global Environment Fund and several energy-targeted programmes), United Nations Industrial Development Organization (UNIDO), United Nations Children’s Fund (UNICEF), the Regional Offices, etc., have been involved in the process. Some participants suggested that the United Nations should consider setting up a specialized agency, especially in the field of renewable energy technologies. The essential role of cooperation among developing countries on a regional basis was also mentioned.

Technology alone cannot solve all problems. An appropriate institutional environment (including regulatory, normative, financial and legislative measures) is required for the market to adopt sustainable energy solutions and this is a task for governments. Rather than considering the environment as a constraint, problems must be turned into opportunities. Studies and experimentation in this field, as well as on social aspects, may be as important as pure technological demonstration. It was noted, for instance, that little information is available on the preferences and priorities of potential energy users in developing countries. Where surveys have been conducted, the results have been quite different from expectations. In order for a market to perform its rationalization role, individual preferences are of paramount importance.

Energy trajectories also influence the way in which development takes place in areas such as: health, gender issues, employment, distribution of wealth. The successful and sustainable resolution of energy issues discussed at the thematic meeting will also relieve international tensions and contribute to peace.

Note

1. The report of the associated meeting may be accessed at the following address: http://www.unesco.org/science/wcs/meetings/eur_villa_olmo_98.htm

New materials: their contribution to our future

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The last decade in particular has seen an explosive increase in the rates of design, production and utilization of new materials. The remarkable advances that have been made will continue to pervade every corner of our lives and will increasingly influence the manner in which we live, work, travel, communicate with each other and spend our leisure time. These advances have occurred right across the spectrum of physical, chemical, biological and engineering sciences so that it is now feasible to design, synthesize and to characterize substances on the molecular level, to assemble them into novel structures and to bring them quickly into everyday use in new applications. Further progress in almost every field of human endeavour depends on the availability of new materials: their production is now a key enabling technology for the future.

Scientists work in the atomic and molecular world and their task in making new materials is to assemble combinations of the atoms of the more than 100 known chemical elements into larger structures that constitute useful materials. Advances in a range of scientific disciplines mean that materials that will display particular desirable macroscopic properties and functions can now be designed at the atomic level. The use of scanning tunnelling and atomic force microscopes makes it possible to ‘see’ atoms and even to manipulate them around on surfaces. Computational techniques for the atomistic simulation of chemical substances and processes have now come of age and are established as essential predictive tools in materials development. They can greatly reduce the expense and effort that has been traditionally required in prototype synthesis, evaluation and testing. Chemists are now building molecular-level devices (MLDs) in which each of a discrete number of components plays its individual part so that the assembly, either at the molecular or supramolecular level, can accomplish a prescribed function.

Education

The crucial need fully to understand the atomic world if our current rate of progress in the utilization of new materials is to be maintained makes education to the highest level in the fundamental sciences of physics, chemistry and mathematics more important now than ever before. For this reason the decline evident in many countries in the number of students taking these subjects at both secondary and tertiary levels is of serious concern and requires urgent remedial action on the part of those setting educational policies. The recruitment of well-trained, qualified and enthusiastic teachers is an obvious prerequisite. The fact that these subjects are often seen as difficult is one possible reason for this decline. The poor image of chemistry, particularly with young people, as a commercially driven, resource-depleting and polluting activity is certainly another. It is the clear responsibility of all those engaged in the teaching and practice of chemistry to promote a positive image of the subject, particularly in terms of its many achievements in the materials area, and to ensure that only best environmental practice is followed in future commercial plants.

In addition to education in the fundamental sciences a genuine multidisciplinary approach is essential in the education of young scientists and engineers if they are to realize the full potential of new materials and fit easily into the teams of materials scientists that work in modern industries. Educational programmes and research initiatives must seek to build and encourage a real multidisciplinary ethos between subjects and institutions. The research programmes at large-scale facilities, such as the synchrotron radiation sources that are essential for the characterization of materials, promote and foster this ethos and could be further promoted as a focus for such developments in the future.

Applications

Advances in experimental, theoretical and computational techniques have opened up new horizons in the world of materials. Supramolecular chemistry, the designed chemistry of the non-covalent bond, designs molecules to mimic life through their interactions using the same forces as operate in biology. One of the objectives is self-assembly and, in principle, quite complicated chemical entities can result from mixtures in which the molecules are designed to interact in this way. In combinatorial chemistry a large array of molecules is made from a limited set of components combined differently then screened for desired properties. The presence of new materials is now ubiquitous and it will be possible here only to briefly touch on some specific examples drawn from the more obvious areas in which they have a major influence.

Nanotechnology

This covers a whole spectrum of science incorporating molecular structures that are 1-100 nanometres in size and offers new perspectives in improving existing technologies. Nano-powders will provide radically new ceramics, catalysts, lubricants and coatings. Self-assembly of molecules into larger structures will revolutionize syntheses: early applications are likely to be in electronics and to include the production of very finely divided materials showing quantum effects.

Molecular imprinting in polymers (MIPs)

These are prepared by forming a cross-linked polymer around template molecules. The resulting cavities have shapes, sizes and functionalities that are complementary to those of the template. They can therefore provide unique recognition with antibody-like selectivity. They are used for separation, purification, selective detection, pre-concentration and in capillary electrophoresis and offer the potential of incorporation into diagnostic kits.

Porous inorganics

Porous inorganic materials form the basis of most absorbents, separants and concentrants used for the controlled delivery of active ingredients in consumer goods and pharmaceuticals. They are also used in waste recovery and are vital for the effectiveness of many commercial catalysts. Advances will come in our ability to design, predict performance and control the synthesis and macroscopic forms of new micro- and meso-porous materials. Advances in HT chemical reactor systems, fuel cells and electrochemical reactors will depend on the development of inorganic components that can operate at sufficiently high temperatures.

Electronics and communications

The new technologies used in these areas provide the most visible and widely known applications of new materials. Brighter and faster liquid crystal displays based on new liquid crystalline materials will displace our traditional screens. Miniaturization and enhanced performance in the computer industry will exploit organic conductors: perhaps the greatest challenge here is the design of self-assembling molecular computers. The speed and efficiency gains in fibre-optic communication will continue to depend on challenging functional materials such as non-linear optic materials. Rapidly developing printing and imaging technologies will demand novel synthetic colourants and formulation processes.

Energy generation and storage

The energy requirements of the world will continue to increase, making new and sustainable technologies for the generation, storage and transport of energy essential. The materials challenges for high-temperature solid oxide fuel cells and for the direct methanol fuel cell are now well defined. New catalysts and the ability to make ceramic membranes are being developed. Improved batteries for applications ranging from portable electronics to vehicle propulsion and peak-shaving of power demands will find universal use.

Medicine and health care

The ever-increasing contributions of high-technology science to medical practice will continue. Biocompatible materials, surface modifications and coatings are required for the production of artificial tissues, bone, implants, grafts, joints and medical devices. Rapid diagnostic kits, including those sold over the counter for self-diagnosis, will become commonplace. Biologically active electrochemical sensors will be developed to provide therapy, preventative action and biofeedback to controlled drug delivery systems such as electrophoretically assisted transdermal patches. Nanoscale chemistry will lead to new devices for monitoring specific functions and disease progression.

Transport

Here the need is to reduce energy consumption and the pollution caused by exhaust fumes. The lightweight engineering materials required range from composites for applications in power units and vehicle interiors to structural components designed to reduce injuries by absorbing the energy of collisions.

The environment

Many pressures, including resource conservation and cost reduction, combine to drive research efforts to find simpler materials that can easily be recycled. The ‘green’ chemistry initiative, which seeks to lessen or eliminate the use of hazardous substances and to promote source reduction, will lead to innovative cleaner methodologies and more specific and careful control of the production of materials in chemical syntheses.

Conclusions

The science of new materials is an emerging, exciting and productive area of modern science and engineering. The development of new materials will be the key enabler in a wide range of new technologies that will impact across the entire spectrum of human activity. It merits the same support as fields such as information technology and the biosciences, and a sustained and broad research effort will be essential if it is to continue to contribute to the improvement of our lives and expectations. It is truly multidisciplinary in nature and this ethos must be unambiguously incorporated into educational and research programmes if these are to be successful. It has an extraordinary potential to produce a wide diversity of advances and opportunities but will require a commensurate level of investment in fundamental and technological research and development if this potential is to be fully realized.

Acknowledgement I wish to thank the Royal Society of Chemistry for permission to base part of this presentation on a ‘Scientific Forward Look for Chemistry’ compiled by Dr Mario Moustras as a part of its Foresight programme. For further details of the programme see the RSC website (http://www.rsc.org).

Challenges for polymer science in the 21st century

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Polymer science has been one of the most rapidly developing fields in natural sciences in the second half of the 20th century. This is due to the unique position of this field at the boundary between physical and organic chemistry, condensed matter physics, molecular biology and different branches of materials science. As a result, all the most important developments in this field have essentially influenced polymer science as well. For example, the discovery of the structure of the double helix of DNA in 1953 stimulated the development of a large field of biopolymer research which now constitutes one of the most important research directions of polymer science.

This diversity in disciplines having some relation to polymer science is also manifested in the diverse character of applications in this field. These applications range from the use of polymers as construction materials (plastics, rubbers, fibres) and for functional purposes (paints, superabsorbents, membranes, optically active media, all kinds of ‘smart’ materials) to the explanation of the molecular origin of processes in living cells.

For a polymer scientist in the 21st century, successful research will depend on his ability to accumulate knowledge from all the above-mentioned different disciplines and to use this knowledge in a wide range of applications. This creates special requirements for optimum educational programmes in polymer science.

As to the place of polymer science on the ‘map of sciences’ of the 21st century, its important and key position will be ensured by its numerous applications (mainly molecular-biological and molecular-electronics in nature) and by its role in connecting different disciplines.

The importance of interfaces in materials science

Roger G. Horn
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In this talk I want to discuss one area of importance in materials science, namely interfaces. I will use a few simple examples from current topics in materials science to illustrate why I claim that interfaces are important and I will then look a little bit into the future to explain why I think interfaces will continue to be important, and indeed of growing importance, in the science of materials. Because of this, I suggest that, in studying the science of new materials, we must continue to pay attention to the science of interfaces.

The science of interfaces encompasses detailed investigations of the atomic-scale structure of interfaces and the physical and chemical interactions between different materials across interfaces. The manifestations of interactions across interfaces include adhesion and friction, both of which are very familiar and yet they are poorly understood at a microscopic level. In addition to the technological importance of these phenomena, there is a lot of exciting science that remains to be done in these areas.

Why are interfaces important? There are many answers to this question, but in this short talk I will choose just three simple examples.

First, when a material consists of small grains, for example a ceramic or a polycrystalline metal, the interface properties at the boundaries between grains have an important effect on the material properties. In a metal, for example, a theoretical calculation based on the known strength of interatomic bonds would predict a strength of the material that is orders of magnitude larger than the measured value. In practice, the strength is limited by plastic deformation of the metal and it is now well understood that plastic deformation occurs only because defects in the crystalline packing of the atoms facilitate the rearrangement of the crystal into a different shape when it is subjected to a stress. This occurs because certain defects (edge dislocations) can move easily through the crystal when it is subjected to stress. However, if the metal consists of many small crystals, as is usually the case, it is not so easy to deform each one of them because the edge dislocations become blocked by the interfaces (grain boundaries) between the small crystals. In that case the metal is less easily deformed; in other words, it becomes harder. Hence the hardness of metals, and many associated phenomena such as work hardening and annealing, depend very much on the presence of interfaces within the metal's microstructure.

A second example occurs when a material consists of more than one component, such as in a composite material. The way in which those components are joined together has a very important effect on the material's properties.

Composite materials are constructed of more than one component, with the purpose of combining favourable properties (or overcoming unfavourable properties) of the component materials. A common example is fibre-reinforced polymer (FRP) materials (e.g. fibreglass): the high strength of the fibre material is utilized, but its brittleness is overcome by embedding the fibres in a polymeric matrix material.

Some properties of composites are determined by simple averages of the properties of the component materials. For example the density of a composite is easily calculated from a weighted average of the densities of the two materials. Because of this, its value must always be intermediate between the two component densities.

However, consider the toughness of a well-designed fibre-reinforced composite material. The toughness is a measure of the energy that is required to break a sample. A brittle material like glass has a low toughness, but materials like polymers are much harder to break and they have high toughness. A fibreglass composite is designed to exploit the polymer's toughness, but, as Table 1 shows, it does even better than this: the toughness is much higher than the weighted average of the toughness of the component materials.

How is this spectacular enhancement accomplished? The answer lies in the fact that the toughness is determined largely by the properties of the interface between the fibre and the matrix, rather than the materials themselves. Detailed investigations of the mechanisms by which an FRP composite breaks show that a large amount of energy is consumed by frictional forces between the fibre and the matrix. Understanding this vital role of the interface allows the strength and toughness of the FRP to be 'tuned' if the failure mechanisms are identified and the properties of the interface are controlled.

A third example of the importance of interfaces occurs when the interface itself bestows certain functional properties on the material. Arguably the most important example of this is the interface between different semiconductor materials (or differently-doped semiconductors) which can rectify current. Applying a bias voltage in one direction allows many charge carriers to cross the interface, giving a large current, but when the bias voltage is applied in the reverse direction, few charge carriers cross the interface and the current is low. The operation of diodes and transistors, and hence all the myriad microelectronic devices that are in use today, depends on this property of the interface.

What of the future? Almost all technological developments hinge on developments in materials science to produce the materials that are required to make them work. And it is clear that we are seduced by, and rapidly become addicted to, almost every new technology that comes along. After living in a house with a roof and windows in the walls, who would go back to living in a rough shelter or a cave? After driving a car, who goes back to walking or riding a bicycle? After flying across the world, who travels by boat? After using a computer to write documents and draw diagrams, who uses a pen for these tasks?

There is an interesting question about whether we actually ask for these new technologies, or whether they are pushed on to us by companies marketing their inventions and developments. However, whatever drives the process, it is clear that materials science marches on like an army of ants. Although we seem to accept this inexorable 'progress', it comes at a price. We degrade the environment, our lifestyles become

Table 1.

Material	**Toughness** (energy required to break unit area, J/m^2)
Typical fibre material	10
Typical polymer matrix material	100-1 000
Well-designed fibre-reinforced polymer composite material	100 000

more sedentary and sometimes we poison ourselves with new materials and their by-products. For the reasons posed in the previous paragraph, I do not believe that we are likely to stop the flow of new materials into our lives. However, what we can and must do is ensure that new materials perform their functions with the utmost efficiency. By this I mean that their benefits should be maximized and their drawbacks minimized. Materials for transport must have maximum strength and minimum weight; manufactured materials must have desired structures but minimal energy costs in their production; microelectronic materials should have minimum size and power consumption; synthetic materials must be produced with minimal amount of unwanted by-products; materials should have long lifetimes and maximum potential for recycling; and so on.

Materials scientists will continue their search for new materials having the utmost ‘efficiency’ in this general sense. Can we predict which avenues they will be exploring? One possibility is that we will search for more complex composite materials. To date there has been a lot of work done on developing composites of two components, with considerable success in producing a wider variety of useful materials than is available from single-component materials. Perhaps in the future we will investigate materials of three or more components, which will open up even richer possibilities for achieving favourable properties and minimal drawbacks. If so, then the interfaces will also be more complicated and, for the reasons outlined above, I have no doubt that they will be of considerable importance.

A second avenue that is of considerable current interest is the development of materials that are constructed from a microscopic scale. We hear phrases like molecular architecture, supramolecular chemistry or nanotechnology. With increasing miniaturization in microelectronics and sensors, and with discussion of building materials up from molecular or microscopic components, two aspects of interfaces become extremely important. The first is how the tiny building blocks of these new materials interact with each other via physical forces when they are assembled into a larger whole. This question has fascinated colloid scientists for many years and one of the interesting observations is that the interaction between microscopic objects depends strongly on the nature of the surrounding environment – whether it is air, vacuum, water, a lubricant, etc. In this sense the interface between the object and a surrounding fluid medium is itself of considerable importance.

The second aspect of interfaces that becomes more important with miniaturization is that the ratio of ‘interfacial’ material to ‘bulk’ material increases as the size of the building blocks decreases. Let us suppose that an atom within a few atomic diameters of a boundary is affected by its proximity to that boundary and can therefore be categorized as ‘interfacial.’ We can then do a simple calculation to find what proportion of material fits this category. For the sake of simplicity, suppose that our building blocks are cubes. Table 2 shows the percentage of material to be found within 0.5nm of a boundary between cubes of various sizes (1nm is one millionth of a millimetre).

Table 2.

Size of cubical ‘building block’	**Percentage of material that is ‘interfacial’**
10µm	0.03%
1µm	0.3%
100nm	3%
10nm	27%
1nm	100%

Clearly, if materials are built up from such microscopic building blocks, an understanding of interfaces and interfacial material becomes critical to understanding the properties of the whole material.

Small-scale materials science with large-scale facilities

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Comprehensive studies of the properties of new materials routinely involve the use of large-scale materials science facilities, such as synchrotron x-ray and neutron sources, as well as muon spin rotation laboratories. These large facilities function in a manner that is intermediate between those which are normally thought of as ‘big science’ facilities and small-scale research facilities typical of university-based materials research laboratories.

These sources are expensive and few therefore exist; these are operated as either national or international facilities. However the user community associated with many such large laboratories ranges from about 100 to 1 000. Because they accommodate so many users, researchers have relatively little time available at the facility and making progress requires that the experiments fit into a hierarchy of studies in which the new materials have already been well characterized by traditional small-scale materials science techniques, such as heat capacity, resistivity and susceptibility, before the experiment at the large-scale facility is attempted.

The materials research community expert in these neutrons, synchrotron and muon techniques is relatively small. The large majority of users of these facilities will require expert collaborators from the facility or elsewhere. Efficient use of these laboratories requires collaborative programmes that ensure these facilities are part of a coherent plan that meshes materials preparation and characterization into the use of large-scale facilities.

Porous solids, environment and strategic developments

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The best-known porous solids are natural and synthetic zeolites which are aluminosilicates. On the atomic scale, their crystal structures show empty tunnels or cages, with dimensions in the range of 8-10Å. These pores can accept guest molecules and this property has been widely used in the domains of petrochemistry, catalysis, ion exchange and gas separation. Such properties have created an increasing demand from the concerned industries for tailor-made compounds for more and more specific applications. Therefore, there has been enormous growth in the chemical diversity of open framework inorganic materials during the 1990s. Most of them are based upon oxygen-containing materials, especially phosphates, but there is a growing list of examples based upon other chemistries (for example, oxide fluorides, nitrides, sulphides).

At the beginning of the 21st century, and owing to the environmental problems which every day take on increasing importance, porous solids, thanks to their capabilities of absorption linked to the existence of the pores, can provide more than before a solution to many problems: elimination of toxic species, storage of radioactive species, etc. This needs a real design of particular solids for given applications and, therefore, a deeper understanding of the formation of these solids to manage the synthesis of solids with dimensions and shape of pores adapted to a particular purpose.

Strategic developments have just been discovered which open the way to solving some environmental problems.

Computer modelling of materials on the atomic scale

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One of the key advances over the last 20 years in general scientific methodology has concerned the ability to construct increasingly accurate models of molecules and materials at the atomic level. One recent application of this exciting field in the science of materials is the use of atomistic modelling techniques to reveal the complexity and beauty of the structures of complex crystals and glasses. Of major significance in the industrially important field of heterogeneous catalysts are surfaces and surface processes, including molecular adsorption and reaction. Modelling methods allow us to investigate the movement of atoms in materials. The continuing spectacular growth in computer power is likely to influence future developments in the field.

Thematic meeting report

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The thematic meeting was well attended and comprised six invited presentations, as listed in the final programme. These were interspersed with questions from the participants and were followed by a lively discussion period.

The meeting opened with an overview of the ubiquitous part played by new materials in science and in existing and emerging technologies. This stressed the atomic nature of all materials and included many examples of specific challenges in design and synthesis facing areas such as transport, energy storage and generation, electronics, medicine and health care, communications and the environment. Some more speculative ideas based on miniaturization, smart materials, molecular machines, self-assembling systems and the applications of nanotechnology were also discussed. There followed a description of the importance of polymeric materials since their discovery and very rapid development and of their likely greatly increased utilization in the 21st century especially in the molecular biological and molecular electronics areas.

The multidisciplinary nature of polymer science, necessitating as it does the integration of chemistry, physics, molecular biology and materials science, was emphasized, as was the attendant need for a distinctive educational programme that should be largely fundamental and firmly laboratory based. The importance of our scientific understanding of interfaces as a key to the continuing development of new materials was then considered. This was important in the behaviour of composite materials and even more complex composite systems are likely to be developed and used to replace monolithic materials across a range of applications. The role of interfaces is crucial to the mechanical strength of many ceramics and in the functionality of some microelectronic devices. With the increasing trend towards miniaturization and in the burgeoning area of nanotechnology the importance of interfaces will increase because, as the component size decreases, a greater proportion of the material exists in or near to an interfacial region.

Next, the meeting heard that a full characterization and understanding of new materials required the routine use of the large shared facilities such as neutron and synchrotron radiation sources. These were essential to probe structures at an atomic level but could only be provided on a collaborative basis. Work at such centres was particularly appropriate to the interdisciplinary nature of materials research and had proved to be extremely beneficial in the training of young researchers. There followed a presentation on the nature and role of micro- and meso-porous solids that emphasized their extraordinarily varied usage in a range of everyday applications in assisting with the preservation of the environment and in the commercial production of essential products for life. The methods available for the production of these materials were discussed with particular emphasis on the newer methods for synthesis of the more complex systems. The meeting then learned of the very significant and unique part played by atomic computational techniques in the understanding of the structure of materials and of their properties and behaviour. The range of techniques and the computational power now routinely available meant that these techniques had come of age. Their role in the design and in the prediction of the properties of new and modified materials was becoming increasingly their most important contribution. The extremely wide range of materials to which these techniques have been applied was described and reference was also made to the many other computational techniques that are used in the design, synthesis and characterization of new substances. The use of computers and their impact will certainly increase in the future.

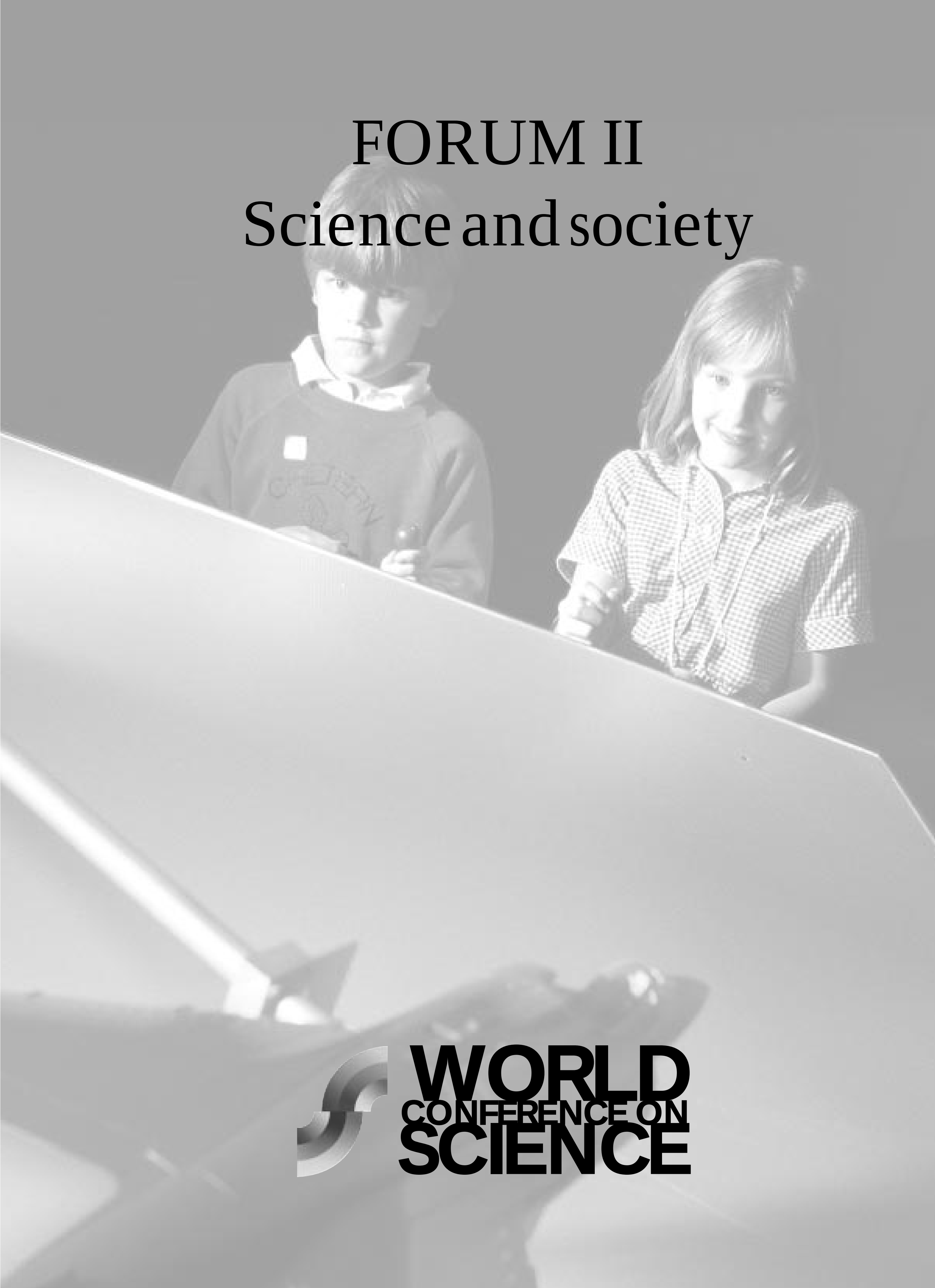
The discussion period proper opened with the theme of education where the need for a materials scientist to have a good grounding in the fundamental concepts of physics and chemistry was recognized. The decline in the number of students entering these subjects in many, though not all, countries was noted and possible reasons for it discussed in the general context of the current public perception of science. Suggested remedies for this included encouragement and incentives to ensure the provision of teachers at secondary level who were fully qualified in physics and chemistry. A greater sensitivity to environmental matters, especially in chemistry, and the formation of genuine partnerships with the engineering and medical sciences to make the subjects more attractive to students, would also contribute. It was agreed that chemistry and physics would continue to be of major importance in that they had essential and significant contributions to make to three of the most important forefront areas of current advancement, namely: materials science, information technology and the life sciences. Their roles in these key areas should therefore be introduced at an earlier time into formal lecture courses and particularly in those designed for the teaching of chemistry to non-chemistry majors.

As a forefront area, materials science itself was declared by the meeting to be a vital and varied field, and to be truly multidisciplinary in stature. It requires a wide range of modern techniques, both computational and experimental, for its progress and it will interact with and impact on every major technological challenge in the 21st century. It will be the key enabler in very diverse technologies ranging from miniaturization and measurement, through biomaterials and nanotechnologies to health care and the conservation of the environment. Regarding the latter of these, particular emphasis was placed on its potential contributions to the very major task of maintaining and improving water quality.

With respect to research facilities and training, which for materials science are expensive and require access to large facilities, the meeting strongly recommended the establishment of an international centre. This could be coupled with an international network, whose aim would be to provide access to internationally competitive facilities and training to materials scientists from the developing world.

The participants discussed a number of the specific areas in which new materials were required and saw a need for materials scientists to step courageously across existing boundaries between disciplines to find and understand what were the real needs for progress. Two issues which it was felt deserved special support were the search for alternative cheaper catalytic converters for the exhaust fumes from combustion engines and the production of new micro-porous materials for use in the many separation technologies that will contribute to the sustained quality of our environment.

The meeting concluded that the science of new materials was a highly exciting, productive and innovative area of science. The challenges facing mankind all have a materials aspect and a sustained research and development effort into new materials will be imperative. As a forefront area in contemporary science that will certainly increase its impact on all areas of scientific and technological endeavour, the science of new materials merits the same prominence and support as fields such as information technologies and biosciences, to both of which it will make increasingly vital contributions.



FORUM II
Science and society

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FORUM II KEYNOTE SPEECH

Public perception of science: between acceptance and rejection

John Durant

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A few weeks ago Professor Anthony Giddens, Director of the London School of Economics, gave the annual BBC Reith Lectures under the title ‘Runaway World’. Appropriately enough, since they dealt with the theme of globalization, Giddens delivered these lectures both on radio and before live audiences in London, Delhi, Hong Kong, Washington and, finally, London again. As each lecture went out, it was also posted on the World Wide Web as a basis for a global conversation on globalization[1].

In the last of his lectures, Giddens dwelt on what he termed ‘the paradox of democracy’. Roughly speaking, by this he meant that generally people who do not have democracy seem to want it a great deal but, when they get it, they do not seem to like it very much. I quote:

‘The paradox of democracy is this. On the one hand, democracy is spreading over the world… Yet in the mature democracies, which the rest of the world is supposed to be copying, there is widespread disillusionment with democratic processes. In most Western countries, levels of trust in politicians have dropped over past years. Fewer people turned out to vote than used to, particularly in the USA. More and more people say that they are uninterested in parliamentary politics, especially among the younger generation. Why are citizens in democratic countries apparently becoming disillusioned with democratic government, at the same time as it is spreading around the rest of the world?’

What Giddens observes about democracy seems equally true of science. If democracy is, as Giddens asserts, ‘the most powerful energizing idea of the 20th century’, science cannot be very far behind. In the course of our century, science and science-based technologies have transformed ways of thinking and ways of living across the globe. Like democracy, however, science has been rather unequally distributed: some countries have had far more of it than others. And, also like democracy, Giddens’ paradox appears to hold. In general, countries that have little science appear to want more; but those that have most seem plagued with doubt and even on occasion with disillusionment. Here is Giddens again:

‘Some very interesting findings are revealed in the opinion polls carried out in different Western countries about trust in the scientific community [government]. People have indeed lost a good deal of the trust they used to have in scientists [politicians] and orthodox science policy-making [democratic procedures]. They haven’t lost their faith, however, in science itself [democratic processes]. In a recent survey in the USA and the major West European countries, well over 90% of the population said they approved of scientific methods [democratic government] Moreover, contrary to what many assume, most people aren’t becoming uninterested in science [politics] as such. The findings actually show the reverse. People are more interested in science [politics] than they used to be’.

I should make it clear that what I have done in this quotation is to insert words to do with science wherever Giddens actually wrote words to do with democracy. Of course, this has changed the meaning of his statement completely; but interestingly, the result is something that I take to be a pretty accurate summary of recent changes in public attitudes towards science and scientists. Only a couple of generations ago, scientists were respected authority figures in Western society. They were the ‘men in white coats’, who were regularly wheeled out to adjudicate on complex technical matters of all kinds; and, in general, it seems that the public were perfectly happy to defer to their expert judgements.

Today, matters seem very different. Across the industrialized world, trust in scientists and scientific institutions appears to be declining. To be sure, the scientific men and women, who may or may not be dressed in white coats, are still regularly wheeled out to address complex technical matters of all kinds, but frequently, they find themselves pitted against one another, or against non-scientific challengers who dispute their expert points of view. On matters as varied as energy, the environment, genetically modified (or GM) foods, cloning and many other issues of public importance, it's no longer obvious that even a consensus of scientific expertise is necessarily sufficient to carry the day. This is because the public is more and more unwilling simply to defer to expert judgements. Instead, the public increasingly takes to itself the right of adjudication between rival forms of expertise.

A good illustration of this sort of public scepticism is provided by recent European debates about new gene technologies. For some years, large sections of the European public have been ambivalent about many of the alleged benefits of these technologies, particularly when they are applied in agriculture and animal husbandry (Durant *et al.*, 1997, 1998). A series of regulatory initiatives at both the national and European levels, coupled with repeated expert reassurances about the safety of GM foods, have notably failed to calm public fears. In the UK, for example, the sheer strength of negative public opinion in recent months has led industry and government to retreat from what had seemed likely for some time to be a policy of fairly rapid introduction of GM foods into the British marketplace.

Faced with increased public scepticism of this kind about expert scientific judgements, many scientists fear that what they may have to deal with is straightforward anti-science. But this is like saying the distrust of politicians is symptomatic of dislike of democracy. Giddens' point is that the very same people who profess not to trust their political leaders also profess continuing commitment to the democratic ideal. And so it is also, I believe, with science. While is it certainly possible to find isolated pockets of ideologically motivated anti-scientific opinion – for example, among certain types of fundamentalists, both West and East; and, according to Sergey Kapitza, among some sections of Russian society in the immediate aftermath of the collapse of the Soviet Union – in general, mass publics which have resisted particular scientific judgements in the modern period have not done so in the name of alternative, explicitly anti-scientific worldviews.

This point can also be illustrated from recent European debates about new gene technologies. Most of the Europeans who are firmly opposed to the use of gene technology in agriculture are equally firmly in favour of the use of the very same gene technology in many branches of medicine (for example, in genetic testing, or in the production of new drugs and vaccines). What's more, many of the arguments that are currently being deployed by critics against the use of gene technology in agriculture – for example, arguments about the possible effects of GM crops on biodiversity, or about the possible effects of GM foods on human health – are themselves scientific both in form and content. Virtually all the non-governmental organizations that are currently campaigning internationally against particular types of gene technology are doing so on grounds that are – in various ways and to varying degrees – scientific.

If it is not anti-science, then what is it that underlies increasing public scepticism about scientific expertise at the close of the 20th century? Several obvious reasons come to mind. First, our 20th century has witnessed an extraordinary range of scientific and technological developments, both for good and ill. This has been the century of the antibiotic and the atom bomb, transplant surgery and Chernobyl, DNA and dioxine. At the close of such a century, it is scarcely credible to ask the public to accept everything that may be offered in the name of science as an unalloyed blessing. A second, related point is that, along with the relentless expansion of science and technology and the rapid increase in standards of living in many parts of the world, there have come a number of frequently unforeseen, unattributable and ill-defined 'risks' – to the global environment, for example, and to human health – that at times have made science itself seem like a poorly controlled experiment conducted upon society as a whole. Third, while science and technology have demonstrably benefited some parts of the world enormously, they have signally failed to have anything like the same impact on others. The growing gap between the developed and the developing worlds through much of the 20th century has also been a growing gap between the scientific and technological 'haves' and the scientific and technological 'have-nots'; and this gap has served to raise questions about the long-standing promise of science to ameliorate the human condition.

While these are important factors, I think there's an even more fundamental reason for growing public scepticism about scientific expertise. This has to do with the very same forces that have led to increasing disillusion with democratic politics and politicians. For Anthony Giddens, it's the very processes of globalization – particularly the undermining of tradition and the growth of global communication – that lie at the heart of the paradox of democracy. As Giddens puts it, 'The communications revolution has produced more active, reflexive citizenries than existed before'. Such citizenries are increasingly reluctant simply to accept on trust what their political masters choose to tell them. Compared with their parents and grandparents, today's citizens are more questioning of what their political masters are up to. In the same way, I believe that increasing awareness of science and scientific issues, coupled with increasing access to information about these issues, are what underlie increasing public scepticism about scientific expertise. It is not ignorance but rather familiarity that breeds contempt.

To some scientists, it may be tempting to see in this conclusion a welcome excuse for keeping their professional heads down – that is, for ceasing to communicate with the public about their work in the fond hope that, so far as science and the public are concerned, ignorance is bliss. To any scientist here who may be inclined to such a view, I can only say: ‘Think again’. For one thing, the genie of the information society is well and truly out of the bottle. In the modern, globalizing world, there is simply no way back to a quieter, less communicative, more deferential world in which nobody questions the judgements of scientists because nobody either knows or cares very much about what they are doing. In the information society, scientists who refuse to talk about their work in public are far more likely to be presumed to have something to hide than they are to be presumed innocent. The choice lies not between the safety of silence and the danger of communication but rather between the safety of open and honest dialogue and the danger of old-fashioned ‘public relations’.

But there is another, less pragmatic reason for not simply wishing that, so far as science and the public are concerned, ignorance were bliss. For the plain truth of the matter is that in a democracy a sceptical and questioning attitude towards elected politicians is a thoroughly healthy thing. Equally, in a democracy, a sceptical and questioning attitude towards experts of all kinds is a healthy thing. Morally and politically speaking, we have no reason to regret the fact that today there is a clear trend towards calling scientists to account in public for their work; nor do we have moral or political reason to wish that scientists were not so often challenged in public to justify their claims against the competing claims of others. Knowledge, as Francis Bacon observed, is power. If today’s enormous-scientific-knowledge-that-is-also-enormous-power is to be harnessed democratically, then it is essential that it be subjected to close and careful public scrutiny.

How is this to be done? Clearly, there are risks to be avoided. Not everything that goes on in the name of science communication is entirely conducive to the public good. The extended timescale of scientific enquiry does not always sit comfortably with the compressed timescale of the news media. Equally, the complexities and uncertainties of much scientific research do not lend themselves at all well to the sloganizing and stereotyping of so much tabloid journalism. As British biotechnologists and biotechnology policy-makers have learnt to their cost in recent months, it can be difficult to create public spaces that are conducive to the kind of debate that many scientific and technological issues deserve; and even when such space has been created, it can quickly disappear again when the heat is on and news managers are looking for ways of keeping issues high on the public agenda.

In the face of growing public disenchantment with the workings of democracy, Anthony Giddens advocates not the abandonment but rather the further strengthening of democracy, a process he refers to (with intentional irony) as ‘the democratization of democracy’. Giddens suggests that democracy needs to be broadened to embrace new forms of international partnership and deepened to include new methods of engagement between citizens and the democratic process at local, regional and national levels. Once again, I believe that the analogy with science holds true. Faced with growing public distrust of science and scientists, our task must be not to isolate and insulate science from the public, but rather to open it up to new forms of public engagement and public scrutiny. Such opening up must be not only national but also international, for science is one of the least parochial of all human activities.

There are signs that this kind of opening up is already under way in several different parts of the world. In recent years, alongside the very many and welcome initiatives in what may be termed more traditional forms of science communication – lectures, publications, broadcasts, festivals, etc. – there have emerged several new forms of science communication based on the principle of constructive dialogue among citizens and between citizens and scientists. Citizens’ juries, deliberative opinion polls and consensus conferences are just three of the better-known forms of dialogue-based communication that have been experimented with in different national settings. Each sets great store by bringing together groups of citizens for purposes of careful deliberation; and each seeks to feed back the results of such deliberation into the policy process.

Of these three mechanisms of public consultation, it is the consensus conference that was specifically designed to deal with science-and-technology-related policy questions. The originators of this device were the Danish Parliament and the Danish Board of Technology and it is in Denmark that the consensus conference has been most thoroughly explored and exploited. However, since the late 1980s when the Danes first began using consensus conferences as a contribution to national debate and decision-making, this model has been taken up by an increasing number of other countries. In 1994, for example, the first initiative of this kind took place in the UK, where the Science Museum of London organized a consensus conference on plant biotechnology. Much more recently, in May 1999, a second UK consensus conference was held on the long-term management of radioactive waste. Ironically enough, this second initiative took place against the backdrop of an intense public debate about – plant biotechnology! Interestingly, the citizen panel convened in 1999 commented that, in its opinion, many of the difficulties currently being experienced in the UK debate on GM foods might have been avoided if only more attention had been paid to the recommendations set out on this subject five years earlier in the citizen panel report on plant biotechnology.

This World Conference on Science provides a unique opportunity for the international scientific community to review the global state of health of science at the close of the 20th century. Rightly, UNESCO and ICSU have given equal prominence in the programme to the achievements of science itself and to the place of science in society. In its opening message to the Conference, UNESCO looks forward to a meeting in which 'the spirit of science for society and society for science' will prevail. There is much wisdom in this formulation. Science cannot be 'for society' unless society is 'for science'; but equally, society cannot be 'for science' unless science in turn is 'for society'. Either we have both of these happy states, or we have neither. The question is: how shall we secure both?

It is only through constructive and continuing dialogue between science and society that a partnership of this kind can possibly be sustained. In our rapidly globalizing world, we need to put renewed effort into the dialogue between science and society if we are to have any chance of creating a future in which the one can properly serve the interests of the other. I believe the time is ripe for initiatives at the international level that will help to improve science communication globally. No one individual, country or continent has all the answers. What is needed is a willingness to share experience, to give from what we have learned and to learn from what others have given. To do this, new international forums for exchange of ideas and best practice in science communication are urgently needed. What better place to start inventing these forums than this, the World's first Conference on Science.

Note

1. See http://news.bbc.co.uk/hi/english/static/events/reith_99/default.htm

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FORUM II KEYNOTE SPEECH

Science for development

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Building capacities in science

Science is the study of nature and the environment around us. Science enables us to know, to understand nature's secrets. It allows us to predict with a degree of probability of certainty that some events will take place when certain reactions are put into action. Science allows us to understand our natural system and to predict why we behave the way we do. Science is therefore an accumulation of knowledge which, when put together, allows transformation of raw materials into usable goods. We therefore study science in order to assemble knowledge. We use knowledge to produce goods and services. Science and knowledge go together but are not identical. Since knowledge creates wealth and a lack of it translates in most cases in the modern world into backwardness and poverty, it is therefore important to enquire into how science and knowledge are generated.

The traditional learning process requires that we expose students to science at a tender age. The early awakening of a child's mind to be sensitive to the environment around it is today very well accepted as the proper approach to learning science. In doing so, a child is taught to recognize ideas and concepts. Through playing with educational gadgets, children develop manipulative skills. Learning science therefore starts when a child is still with its parents. Differences in societal settings and parental ability to explain science can therefore create a difference in learning of science.

However, this disability may not be serious because it can be overcome by schooling. The early years of schooling are essential for the teaching and learning of science because they correct the mistakes made by parents. Provision of well-trained science teachers is essential to science learning. Furthermore, teachers must be provided with tools and equipment to teach science. Unfortunately, most schools in the developing world neither have well-trained science teachers nor the tools or equipment to teach science. As a result, many pupils are turned off by science.

Science learning develops from basic concepts taught at lower levels to abstract ones. As one progresses in learning, new and more difficult abstract principles are learned. A sound basic foundation in science is essential for the average student. Exceptionally bright students are not a major worry, as they will learn science anyway. However, the double tragedy of lack of qualified and dedicated academic staff and lack of science facilities persists both at the secondary and university levels in most developing countries. The teaching and learning of science in the developing world is therefore a task left to exceptionally bright students or those endowed with a large memory capacity. It is this theoretical science teaching that is taking the joy out of learning science in many countries of the world.

In the developed world, young people are not choosing science as a subject any more. This has to do with the image science has created as a result of widely publicized incidences of environmental pollution, nuclear reactor mishaps, dwindling career rewards for scientists and general public perception of science. Careers in computing, business management and economics are more appealing to youth than before. It is also true that the teaching of science is a problem in both the developed and the developing countries. In general, more and more youth all over the world are shying away from learning science. This is an important switch in student attitudes and we have to work hard to win back the interest of future scientists.

Useful science that can be turned into productive knowledge is taught at the university level. Almost all universities in the developing world are modelled after Oxford, Cambridge or Sorbonne universities. They often follow much more strictly the mother university systems, even when the latter have changed these very systems.

University education is universally biased towards the single-discipline subject training. For example, we are trained to be a chemist, botanist, geologist, physicist, historian or philosopher. Discipline-oriented learning is the preferred approach in life and never shall the disciplines mix. It is true that, through disciplines, we have advanced knowledge considerably. However, today's problems require a trans-disciplinary approach. Today's knowledge is assembled like a puzzle. It involves putting together different sciences developed in different disciplines. It requires forming groups as needed and disbanding them to form new ones as scenarios change. A good example of issues that require such an approach can be found in the area of the environment, understanding of natural phenomena such as El Niño and the Southern Oscillation, the synthesis of the anti-AIDS drug, communication and computing, to name but a few.

How are universities faring in meeting the challenges posed to them by both governments and society? Not very well in most cases. It is ironic that institutions that were established to protect academic freedom have to be nudged by governments to allow more freedom. Without pushing, they are unwilling to integrate education, to promote transdisciplinary learning and computation within disciplines into a comprehensive innovation policy that is sensitive to the fact that knowledge production is socially distributed. In Europe particularly, national policies that will enhance the potential of national institutions need to be developed in concert with those of the European Union. For many of the developing countries' universities, access and change will continue to be a problem, not only because capability is lacking, but also because governments there and the institutions themselves still model their scientific and technological universities on assumptions that no longer apply to the kind of scientific and technological activities on which their aspirations depend.

Security through S&T

Today, enhanced national security depends very much on information: what information a nation has, how that information is used in reducing destabilizing environmental degradation and resource distribution and depletion. Historically, the distribution of natural resources has been a basis for conflicts between nations. This no longer happens in the developed world. Paradoxically, the sharing of natural resources found in developing countries remains a destabilizing factor. The rapid development of natural resources of developing countries would significantly contribute to stability and economic growth. National security is found in a healthier, safer state, a stronger economy and improved education and training for the people. National security comes with the ability of a nation to feed its people, a strong social security system that reduces the suffering of the vulnerable groups: children, the old, the sick and the excluded. National security revokes self-glory and aggrandizement and encourages a people-centred system of government.

It is through science and technology (S&T) that the principal ingredients of a healthier, safer state are found. Degradation of the environment through stratospheric ozone depletion, climate change, natural hazards, toxic wastes and food poisoning threaten health and safety. It is only through scientific research that the links can be established and remedies found.

A stronger economy means mass production of goods and services. It requires setting up of management and regulatory priorities. It forces the selection of cost-effective strategies for action and above all it necessitates the identification of problems before they become intractable as a means of avoiding costly remediation. Scientific knowledge provides the basis for responsible decision-making by governments and the private sector. Environmental improvements translate into direct cost savings in health care through cleaner air and water. Reducing waste makes economic sense, saving waste management costs and avoiding indirect environmental costs. S&T is needed to achieve all of the above.

The above few examples illustrate how national security is enhanced through S&T. Nations that do not have a strong S&T base have a false security and are vulnerable to destabilization.

Socio-economic development and poverty reduction

The creation of wealth is today more linked to science, knowledge and information than ever before in human history. A few examples illustrate the link.

- Since the end of the Second World War, technology has been the engine behind the economic growth of the developed countries. It is estimated that, in the USA alone, technology has been responsible for two-thirds of the increase in its economic growth.
- About 70% of goods traded in the world have gone through chemical processes or are chemically based. Examples of such goods are pharmaceuticals, textiles, foods, steel, plastics and other chemically based products. Advances in chemistry and chemical engineering translate into wealth creation for a nation.
- In 1995, revenue generated from global environmental industries stood at US$ 295 billion. The US industries earned US$ 134 billion with the rest of the world sharing the balance. Most of the US$ 161 billion shared by the rest of the world went to Japan and Europe. Trade in environmental industries was estimated to grow to US$ 425 billion in 1997. Africa and the rest of the developing world were consumers of this trade.
- Growth in the information and communication technology (ICT) industry is estimated at 10-20% per annum. The consequences of this new industrial revolution, nebulously called globalization, has deskilling and skilling effects. It has created a new division of labour between the high-technology countries and the rest of the world. The industrial divide is being shifted to a higher technological level.

It is not paradoxical that today those countries that have invested in science have strong economies. However, as the complexity of contemporary S&T unfolds, the proposed solutions to current shortcomings of development appear all the more simple-minded. What is clear is the history of societies that were successful in building up scientific and technological competence. They did so within a broader sense of raising educational standards and changing of values which included a positive attitude towards S&T. Success is also linked to focusing on long-term benefits for all, rather than expecting science to offer short-term technological fixes to complex economic and social problems or merely to aggrandize the prestige of political leaders and their grand projects.

Countering the growing North-South gap in science

Planning strategies have become important tools for decision-making and progress. Understanding the national priorities, and therefore laying the strategic plans for achieving them, starts with a national knowledge assessment plan. It is through national knowledge assessment that national knowledge strengths and weaknesses are revealed. The plan would therefore put forward policies for improving the weaknesses.

Strategic national plans alone without flexible and positive economic policies will not create an environment conducive to wealth creation. Concerted efforts must be made to create economic policies that give incentives to hard work, that reward hard work, that allow risk-taking. Such a policy must reinforce the liberal mode of governance that allows freedom of persons in all essential elements. In other words, democratic principles must be upheld if human resources are to be utilized to the fullest.

Developing countries should take a leaf from the book of mega-business mergers occurring almost every day. Why are we seeing mega-mergers? The basic reason is to reduce cost. Competition has a cost; research and development (R&D) costs are astronomical. By acquiring a competitor who has knowledge or technology, a technological advantage, a company reduces cost.

A second reason relates to generation of knowledge used in doing business. It is no longer sufficient to have an in-house research team. New knowledge is today created everywhere. What makes a difference in high-technology business is the ability to acquire required knowledge and assemble it into a new technology. Several methods exist for acquiring new knowledge. These include R&D groups, universities, think tanks, research institutes and corporate research companies. In addition to having in-house R&D, many industries have cooperation links with traditional knowledge incubators, the universities. Paradoxically, more and more, successful companies today are cooperating in research with their competitors. Joint publications with competitors have become more prevalent than before. Investment in knowledge is therefore shifting more and more to innovation: the ability to assemble new knowledge into a new technology.

Therefore, access to knowledge and expertise, configuring it in novel ways and offering it for sale has become, to my mind, the least costly alternative development path for developing countries. More effort should be put by developing countries into keeping the traditional exchange of scientific information open and free. Developed countries, for their part, have a moral and ethical duty to assist the developing countries by not closing the free exchange of scientific information.

It follows naturally that emphasis on education should also change. We need to train people who are able to understand the frontiers of knowledge, the cutting edge of technology. The new breed of scientists must also be innovators. Proper use of new knowledge through innovation offers the best alternative to closing the gap between developed and developing countries. Having established the priorities and goals, developing countries should not shy away from investing in ICTs. The demand for specialized knowledge requires increasingly sophisticated means of communication and data processing. This, in turn, stimulates the microelectronics, telecommunications and computer sectors. A globalized economy requires a strong ICT sector. The alternative to this is traditional commodity trade with its abundant problems.

Resources for such a bold development strategy may be found from within the country by putting an end to wastage in the economy. It may require taking bold steps to reduce expenditure on some ‘sacred cow’ projects of the government. Above all, it is justified in the sense that such investment will improve educational standards, create new skills and technology and improve communication as well as improving business. In summary, planning and priority-setting, democratic governance, cooperation with competitors, acquisition of diffused knowledge and innovation, as well as investment in ICTs, are some recommended mechanisms for reducing the knowledge gap.

Why hasn’t such cooperation taken place among developing countries? One is fully justified to ask such a question. The answer lies in the South’s perception of itself and its development needs. The developing countries have over-relied on development assistance from the developed countries. The developing world looks to developed countries for leadership, for paradigms of economic growth and for loans to undertake projects. In many cases, some investments already implemented have not been people-centred, but individual- or promoter-centred. Most of those past investments today drain the resources of the South. Recent action of the Group of Seven (G7) to cancel debts of least-developed countries in order to save children in developing countries is a corrective beginning in the right direction.

A second influencing factor in favour of future South-South cooperation is the changed circumstances in which science is conducted in both the developed and developing countries. Scientists in developed countries are under increasing pressure to secure large grants. Staff promotion in the developed countries no longer depends on publications alone. One must show an ability to attract large research contracts. Developed countries' scientists are therefore more and more unwilling to cooperate with unknown scientists from the developing world. Furthermore, such cooperation may not bring big research grants. For their part, scientists in the South, because of their isolation, do not know scientists in the developed countries with whom they can collaborate, even if research funds were to be made available. Knowledge of scientists in the South is an area that needs further strengthening by donors.

A third contributor to lack of cooperation among the developing countries may be found in the policies of the South. Lack of political goodwill between neighbouring countries creates walls against scientific, cultural and economic cooperation. We look to the North for trade offers, we have no faith in our currencies and in the past have discouraged exchange of staff and students. In the area of communication, we have easier telecommunication access with the North than with our neighbours.

Today, we see changes taking place in most of these areas in the South. More and more countries are discovering that they are trading more among themselves than with their traditional partners. The developed countries' markets are becoming more and more difficult to penetrate through set commodity regulations, quotas and other trade barriers.

The falling commodity prices fixed by developed countries' markets have worsened the quality of agrarian farmers' lives in developing countries. In the field of education, the developed countries' institutions have priced themselves out of the market of the average developing countries' households. A heavy debt burden, the change in learning conditions and public pressure have all contributed to that drying-up of sources of cheap money. These factors taken together make me believe that, whether leaders of the South like it or not, they have to cooperate with one another. It is a matter of time until such cooperation becomes deeply rooted.

Perception of science: a valley between North and South

Having been born in rural Africa, I was instructed by my grandparents to see things through reference to supernatural powers. I was taught to show reverence to all life forms, to uphold the sanctity of human beings, to conserve and live with nature and to assist others. The poor were made strong in a society by those who had been given to uplift their status. These values are today fading away but in general still hold true in most rural societies.

From this background, science therefore gives us the power to understand nature. It enables us to assist others and assist nature. Like a magician, a person who has science has a responsibility to society. A magician who misuses power given to him/her by God is killed by the same power, I was taught.

Commercialization of science is therefore alien to most people in Africa. Above all, patent laws are a creation of the West and are not established or effective in most developing countries. We are therefore slow to take advantage of discoveries. Our generosity to others inhibits our aggressive self when it comes to commercializing discoveries or inventions. It therefore goes without saying that most people from developing countries take pride in science when they say 'I discovered that' rather than when they say 'I patented such a process'.

The economic reality of today compels the South to moderate its perception of science. More and more trade in scientific knowledge must come from the South if it is to survive. The form and shape of such trade is difficult for me to predict at the moment, but let us for a moment imagine how such trade would look. I see a South that is more confident in itself, that trades in high-quality, low-volume commodities, that educates its citizens and provides employment for those able to work. I imagine a South that allows free movement of people and goods across its borders, that has no more refugees, that has democratic governments and economic growth per year of 7-10%. Yes, such a South is possible only if we agree to change, to use more fully the benefits derived from education and to encourage science as one of the vehicles of development. That future is for us all to enjoy if the two worlds cooperate to make change a reality. This Conference is looking for change. Through science, change is possible, as has been seen in the 20th century.

Science as an institution: setting priorities in a new socio-economic context

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Science and scientists

A Martian attending this Conference would be puzzled. It would wonder why the Conference isn't a celebration of the many remarkable scientific achievements that have been realized over the past century, but is instead a lament for the weaknesses of science and scientists and an occasion for expressing collective anxieties at what lies ahead.

Speakers have drawn attention to the social responsibility of the scientist. They have deplored the growing commercialization of science. They have expressed disquiet that scientists today are greatly tempted to ignore the stricture that even new knowledge should be treated as a public, rather than a private, good. And they have exhorted scientists not to take their discoveries to the marketplace.

These concerns aren't restricted to those who have spoken here. Earlier this week an International Forum of Young Scientists was held at the Hungarian Academy of Science, at which Professor Leon Lederman, Professor Michael Sela and I chaired the panels on the physical, biological and social sciences, respectively. The Statement[1] prepared at the Forum by the young scientists has been made public at this Conference. It expresses concerns similar to the ones being voiced here. To put it bluntly, it is not merely you who are suspicious of yourselves, young scientists too are suspicious of you! At the Forum they expressed the fear not only that scientists are uninterested in ameliorating the processes which have led to the vast degradation of the ecological landscape and to the persistence of acute poverty among large segments of populations in South Asia, sub-Saharan Africa and Latin America, but that the scientific agenda may itself have contributed to fuelling the processes.

Such accusations may be untrue, but the fears would seem to be real. Scientists, in the eyes of the young at the Forum, are increasingly the problem, not the solution.

As an economist, I am, of course, pleasurably aware that for once the ills of the world aren't being laid at my doorstep, but are instead being laid at yours. But there is here something to worry about. The young are a mirror for us. It may well be that they are more perceptive than us, even if they are no more perceptive than we were when we were ourselves young. So it would pay to explore the source of your own disquiet and that of the young. This is what I intend to do here.

Disclosure versus secrecy

The tension research workers experience, between an urge to disclose their findings to the world at large and the temptation to restrict their spread so as to earn commercial rents from them, is not new; it is age-old. It may be presumed that the individual researcher in part resolves the tension by comparing the relative benefits and costs to him or her of belonging to an institution where the norm of behaviour is public disclosure (with its attendant structure of rewards) and of belonging to a more impersonal commercial world of patents and secrecy. But, typically, the researcher has to choose before making the discovery. For some, the choice is a lifetime commitment to one way of life rather than another. For others, there comes a time when a switch is made, from the world of 'disclosure and priority' to the world of 'secrecy and patents' (of course, the reverse migration is also known to occur). Then there are many who reside in both worlds simultaneously. There is evidence that the latter population has grown significantly in recent years. If industry has maintained campuses for some time, industry has entered the campus in a big way in recent years. The problem is that the relationship between the two is not entirely symbiotic.

Today, we take it for granted that the institution of science has in place incentives which encourage researchers to disclose their findings for public use. But the emergence of those social contrivances which embody those incentives was not inevitable, nor did they emerge easily. It required the collective efforts of scientists and their patrons to establish them. The role of academies in subjecting scientific claims to independent scrutiny, in adjudicating between rival claims for priority and, more generally, in overseeing the quality of those who enter science has been substantial. The social contrivances I am referring to, namely, peer-group esteem, medals, scrolls and the like, are remarkable precisely because they don't involve many resources. To enable the contrivances to be effective has required that a considerable part of a scientist's education involve developing a taste for non-monetary rewards. Such taste has to compete against the financial rewards which may be enjoyed from selling research findings in the marketplace. If the financial rewards increase, and they have increased greatly in recent years, the taste I speak of becomes increasingly a luxury to the research worker, one which he or she is unable to afford. In short, the institution of science embodies a set of cultural values in need of constant protection from the threat posed by the institution of technology.

The culture I speak of is relatively new. It has been suggested that, in Europe at least, norms of behaviour requiring disclosure of scientific findings for public use and the concomitant reliance on priority as an incentive for disclosure were established only in the late Renaissance. It wasn't a coincidence that the first scientific academies were established in several places in the 17th century (see David, 1998).

Secrecy (and the allied social contrivance of patents and profits) is older than disclosure (with the allied social contrivance of priority and peer esteem). The former could be said to be practised in the institution of technology (or technology, for short), the latter in the institution of science (or science for short). Putting it crudely, thus somewhat inaccurately, behaviour is market driven in technology, while in science it is norm-guided. Of course, both institutions produce knowledge. But in the former it is regarded as a private good, while in the latter it is regarded as a public good[2]. The structure of incentives is different in the two places in ways which encourage researchers to regard their produce in accordance with the morals of the institution to which they belong[3]. It should then be no surprise that the character of what is produced also differs. The traditional distinction between science and technology, which sees the former as being concerned with basic research and the latter with applied research, views the two institutions through differences in their products. The viewpoint I am adopting here, of regarding technology and science as social institutions, seems to me to be deeper, because it helps explain why their outputs would be expected to differ.

I don't imagine that science and technology were ever as separate as I am making them out to be. My reason for making a sharp distinction between them, nevertheless, is that it has become harder and harder to distinguish the two in recent decades. The gradual merging of the two institutions has had a cost, as the underlying norms in science have come under stress from market pressures applied by technology. As an institution, science has strong views on plagiarism, publishing with unseemly haste, or announcing findings to the press without having subjected them to peer review. Such behaviour is deemed 'anti-social', because it can mislead not only fellow scientists (who rely upon one another's work) but, increasingly, the public too. Science has had in place self-regulatory mechanisms for discouraging such practice. But if the mechanisms worked well in the past, from all accounts they are not working so well now.

Institutional failure in science and economics

Assuming that my framing of the problem at the root of your disquiet is approximately correct, where does it lead us? I believe it leads us away from the thinking that exhortation is of help. As a social scientist, I have found it useful to work with the hypothesis that the ills we see round us are a reflection of institutional failure. If researchers are increasingly joining technology and, thereby, changing the complexion of the overall research agenda, don't blame the individual researcher, qua researcher; blame instead science for failing to enforce the norms of science and the voting public for weakening the incentives for someone to remain in science. You can do worse than blame the academies and government for this state of affairs.

We face similar problems in the social sciences, most especially, perhaps, in economics. It may be useful to sketch their character. I know them better than the problems you face in science. You can then judge whether they have a familiar ring.

Being economical with one's understanding of social phenomena is a constant temptation for social scientists. Not only are there ethical and political dispositions at play, the desire for publicity is also considerable because the personal gains from publicity are considerable. In the social sciences it is easy to yield to such temptation also because evidence concerning how the social world works is often at best translucent. So you can engage in interpretive battles, not only with others, but with yourself before all else. Who wins depends often on who possesses greater rhetorical skills – frequently, too, on what the press or politicians want to hear. In statistical decision theory, the more a piece of information alters the prior probabilities we attach to events the greater its value. In contrast, in politics and economic journalism reinforcement of prior beliefs is all too frequently awarded a special place of honour. Since economic journalists wield far greater power over the practice of academic economics than do science journalists (at least in the UK and the USA), the temptations we economists face to ignore uncomfortable possibilities is greater. For example, the qualifications which should attend pronouncements on economic policy are frequently absent, even when the pronouncements are made by academic economists. We are able to give in to such temptation because we still don't have the kind of authority structure that was created painstakingly in science, through such institutions as its academies. Economists, and social scientists more generally, are not subject to the kind of discipline that comes with strong and consistent institutional self-regulation.

In the next section I illustrate by means of examples the kind of pitfalls we economists face. You may find parallels in science.

Institutional responses to policy change

Economic pronouncements frequently amount to recommendations for changes in policy. Policy changes may amount to changes in the prevailing system of property rights, alterations to the structure of taxes, undertaking of investment projects, and so forth. This means that a policy change can be thought of as a perturbation to an economic forecast: the economic forecast in the absence of the policy change would be different from the forecast that would be made if the policy change were enacted.

Now it is easy enough to say that a policy change is a perturbation; it is a lot harder to say what the perturbation actually consists of. Any system, human or otherwise, should be expected to respond when subjected to a perturbation. The problem is that policy changes create all sorts of effects that ripple through an economy without being noticed by the public offices, for the reason that there may be no public 'signals' (e.g. publicly observable prices) accompanying them. Tracing the ripples requires an understanding of the way the economy works. It is a difficult business.

The enterprise is made particularly difficult because many economic transactions take place in non-market institutions. A prime set of examples are transactions involving environmental services (e.g. ecosystem services) (Daily, 1997; Dasgupta, 1996)[4]. In poor countries further examples abound. In recent years 'long-term relationships' have been studied by economists and political scientists with the same care and rigour that they used to invest in the study of markets and the state. There is now a large and illuminating theoretical and empirical literature on the wide variety of ways in which people cope with resource scarcity when there are no formal markets for exchanging goods and services across time, space and circumstances (Dasgupta, 1999). The literature offers us a lever with which to predict, in broad terms, the way people, both individually and communally, would respond to policy changes. Unfortunately, the literature hasn't filtered through sufficiently to decision-makers. And it hasn't filtered through because, as an institution, economics hasn't proved sturdy enough to insist that our understanding of non-market institutions is today a great deal firmer than it had been earlier. I want to illustrate what I mean by providing three examples, one a local miniature, the other two altogether grander and near-global.

Management of common property resources

For many years now, the political scientist, Elinor Ostrom, has been studying the management of common property resources in various parts of the world. In her work on collectively managed irrigation systems in Nepal (Ostrom, 1996), she has accounted for differences in rights and responsibilities among users (who gets how much water and when, who is responsible for which maintenance task of the canal system, and so forth) in terms of facts such as some farmers are head-enders while others are tail-enders. Head-enders have a built-in advantage, in that they can prevent tail-enders from receiving water. On the other hand, head-enders need the tail-enders' labour for repair and maintenance of traditional canal systems, which are composed of temporary, stone-trees-and-mud headworks. This means that both sets of parties can in principle gain from cooperation. However, in the absence of cooperation their fortunes would differ greatly. So, cooperative arrangements would be expected to display asymmetries and they do display these[5].

In Ostrom (1996), the author reported that a number of communities in her sample had been given aid by donors so that canals would be improved by the construction of permanent headworks. What could be more desirable than such aid, you might ask? But Ostrom observed that those canal systems that had been so improved were frequently in a worse state of repair and were delivering less water to tail-enders than previously. Ostrom also reported that water allocation was more equitable in traditional farm management systems than in modern systems managed by external agencies, such as government and foreign donors. She estimated from her sample that agricultural productivity was higher in traditional systems.

Ostrom has an explanation for this. She argues that, unless it is accompanied by countermeasures, the construction of permanent headworks alters the relative bargaining positions of the head- and tail-enders. Head-enders now don't need the labour of tail-enders to maintain the canal system. So the new sharing scheme involves even less water for tail-enders. Head-enders gain from the permanent structures, but tail-enders lose disproportionately. This is an example of how well-meaning aid can go wrong if the institution receiving the aid is not understood by the donor.

Resource allocation rules practised at the local level are not infrequently overturned by central fiat. A number of states in the Sahel imposed rules which in effect destroyed communitarian management practices in the forests. Villages ceased to have authority to enforce sanctions on those who violated locally instituted rules of use. State authority turned the local commons into free-access resources. I find it difficult to imagine that such not-so-subtle effects of policy change could not have been foreseen by policy analysts.

Structural adjustment

My second example is altogether more grand and fiercely debated. So, of course, I will be a lot more tentative in what I say. It has to do with the experience people in poor countries have had of structural adjustment programmes, which involved reductions in the plethora of economic distortions that had been introduced by governments over decades.

Many have criticized the way structural adjustment programmes have been carried out. They have pointed to the additional hardship many of the poor have experienced in their wake. But it is possible to argue that structural adjustments, facilitating as they did the growth of markets, were necessary. And it has been so argued by proponents of the programmes. What I want to suggest is that both proponents and opponents of the programmes may be right. Growth of markets benefits many, but it can simultaneously make vulnerable people face additional economic hardship and so increase the incidence and intensity of poverty and destitution in an economy.

How and why might this happen? There are a number of pathways by which it can happen. Here I will sketch one that I have developed in previous writings (for example, Dasgupta, 1993, 1999).

Long-term relationships in rural communities in poor countries are typically sustained by the practice of social norms, for example, norms of reciprocity. This isn't the place to elaborate upon the way social norms should technically be viewed (as self-enforcing strategies). The point about social norms which bears stressing, however, is that they can be practised only among people who expect to encounter one another repeatedly in similar situations.

Consider then a group of 'far-sighted' people who know one another and who prepare to interact indefinitely with one another. By a far-sighted person I mean someone who applies a low rate to discount future costs and benefits of alternative courses of action. Assume as well that the parties in question are not separately mobile (although they could be collectively mobile, as in the case of nomadic societies); otherwise the chance of future encounters with one another would be low and people (being far-sighted!) would discount heavily the future benefits of current cooperation.

The basic idea is this: if people are far-sighted and are not separately mobile, a credible threat by all that they would impose sufficiently stiff sanctions on anyone who broke the agreement would deter everyone from breaking it. But the threat of sanctions would cease to have potency if opportunistic behaviour were to become personally more profitable. This can happen during a process in which formal markets grow nearby and uncorrelated migration accompanies the process. As opportunities outside the village improve, those with lesser ties (e.g. young men) are more likely to take advantage of them and make a break with those customary obligations that are enshrined in prevailing social norms. Those with greater attachments would perceive this, and so infer that the expected benefits from complying with agreements are now lower. Either way, norms of reciprocity could be expected to break down, making certain groups of people (e.g. women, the old and the very young) worse off.

This is a case where improved institutional performance elsewhere (e.g. growth of markets in the economy at large) has an adverse effect on the functioning of a local, non-market institution. To the extent that local common property natural resources are made vulnerable by the breakdown of communitarian control mechanisms, structural adjustment programmes would have been expected to be unfriendly also to the environment and so to those who are directly dependent on them for their livelihood. This is because, when the market value of a resource base increases, there is especial additional pressure on the base if people have relatively free access to it[6]. Structural adjustment programmes devoid of safety nets for those who are vulnerable to the erosion of communitarian practices are defective. They can also be damaging to the natural environment unless the structure of property rights, be they private or communitarian, is simultaneously made more secure. We should not have expected matters to have been otherwise[7].

Free trade and WTO[8]

Recent happenings at the 1999 World Trade Organization (WTO) meeting in Seattle, and the response of those who regard free trade as being good for everyone, offer an example similar to the one concerning structural adjustment programmes. Public discussions on the appropriate role of the WTO are now routinely conducted in terms of an alleged battle between multinational companies and hapless governments in poor countries. But the poor in poor countries are not the same as the governments who rule over them. To be sure, increased international trade has benefited many and arbitrary restrictions on trade have harmed many also. But freeing trade in the presence of incompletely specified and only partially enforced property rights can be predicted to hurt segments of the population and has been known to hurt them. Economic analysis is today capable of identifying the kinds of people who would be expected to get hurt when trade expansion occurs in the absence of appropriate safety nets or compensations.

Consider, for example, the ecological pathways by which deforestation in the uplands of a watershed inflict damage on people in the lowlands (Dasgupta, 1990). It pays to study the pathways in terms of the assignment of property rights. The common law in many poor countries, if we are permitted to use this expression in a universal context, in principle recognizes pollutees' rights. So it is the timber merchant who, in principle, would have to pay compensation to the farmers for the right to inflict the damage that goes with deforestation. However, even if the law sees the matter in this light, there is a gulf between the 'written' law and the enforcement of law. When the cause of damage is hundreds of miles away, when the timber concession has been awarded to public land by government, and when the victims are a scattered group of impoverished farmers, the issue of a negotiated outcome does not usually arise. If the timber merchant is not required to compensate the downland farmers, the private cost of logging is less than its social cost. So we would expect excessive deforestation of the uplands.

We would also expect that resource-based goods would be underpriced in the market. The less roundabout is the production of the final good, the greater would this underpricing be, in percentage terms. Put another way, the lower is the value that is added to the resource in the course of production, the larger is the extent of this underpricing of the final product. Thus, when property rights are not enforced in countries which export primary products, there is an implicit subsidy on the exports, possibly on a massive scale. Moreover, the subsidy is paid not by the general public via taxation, but by some of the most disadvantaged members of society: the sharecropper, the small landholder or tenant farmer, the fisherman. The subsidy is hidden from public scrutiny; that is why it isn't acknowledged officially. But it is there. It is real. We should be in a position to estimate such subsidies. As of now, we have very few official estimates. Since expansion of trade could be expected to increase the commercial value of such primary products as timber, the link between the gains and losses from international trade and the enforcement of property rights should be made to rear its head when discussions on the role of WTO are undertaken. Modern economic analysis can identify scenarios where the gains would be less than the losses. In such circumstances increased trade without a concomitant improvement in the enforcement of property rights would be harmful to a nation in the aggregate.

Even for WTO, governance is at the heart of the matter, not trade.

Technological development and the environment

Economists are tempted not to take economics seriously when their political predisposition or personal ambition assumes centre stage. The examples I have just presented illustrate the kinds of fault policy prescriptions contain when economics is abandoned. There may be parallels in the practice of science. But the examples don't illuminate why the young scientists are suspicious of the enterprise called science. I suggest that their disquiet has to do with the fact that science and technology are not working in tandem with best-practice economics. Let me illustrate this by another example taken from humanity's use of environmental natural resources. I believe the choice is apt, because the young scientists spoke frequently of contemporary environmental degradation and the inability (possibly even unwillingness) of scientists and technologists to prevent it from happening.

As you know, in recent years ecologists and economists have been urging governments and international agencies to make funds available for the purpose of estimating the values of ecosystem services. The question arises, why? Why is there a special need to value those services? Why can we not rely on market prices to guide decisions on the use of global and local ecosystem services, in the way we do for so many other goods and services? Or, to put the matter in another way, why aren't markets an adequate set of institutions for protecting the environment?

The reason is that, for many environmental resources, markets simply do not exist. In some cases they do not exist because the costs of negotiation and monitoring the use of these resources are too high. One class of examples is provided by economic activities that are affected by ecological interactions involving great geographical distances (as in the previous example of the effects of upland deforestation on downstream activities hundreds of miles away); another, by large temporal distances (e.g. the effect of carbon emission on climate in the distant future, in a world where forward markets are non-existent because future generations are not present today to negotiate with us). Then there are cases (e.g. the atmosphere, aquifers and the open seas) where the nature of the physical situation (namely, the migratory nature of the resource) makes private property rights impractical and so keeps markets from existing; while in others, ill-specified or unprotected property rights prevent their existence, or make markets function wrongly even when they do exist (e.g. biodiversity; see Perrings *et al.*, 1994, 1995). In short, environmental problems are often caused by market failure[9].

Since markets cannot be relied upon to provide us with prices which would signal true environmental scarcities, there is a need for techniques which would enable us to determine their scarcity values. A great deal of work in environmental and resource economics has been directed at discovering methods for estimating notional prices, often called accounting prices by economists, which reflect the true social scarcities of natural resource stocks and of the services they provide. The problem is that, for the most part, practical methods have been developed for estimating the accounting prices of 'amenities' (e.g. places of scenic beauty or recreation sites) and relatively few for the multitude of ecosystem services which constitute our life-support system. There is a great deal that remains to be done on the development of techniques for estimating the accounting prices of different categories of resources in different institutional settings.

However, this much is clear. Indicators of social well-being in frequent use (e.g. gross national product (GNP) per head, life expectancy at birth, infant survival rate and literacy) do not reflect the impact of economic activities on the environment. Such indices of the standard of living as GNP per head pertain to commodity production. So they don't fully take into account the use of natural capital in the production process. Statistics on past movements of GNP tell us nothing about the resource stocks which remain. Such statistics do not make clear, for example, whether increases in GNP per head are being realized by means of a depletion of the resource base (e.g. if increases in agricultural production are not being achieved by 'mining' the soil). Over the years, environmental and resource economists have shown how national accounting systems need to be revised to include the value of the changes in the environmental resource base that occur each year due to human activities (Lutz, 1993; Vincent *et al.*, 1997; Dasgupta and Mäler, 2000). We should be in a position to determine whether resource degradation in various locations of the world has yet to reach the stage where current economic activities are unsustainable. But the practice of national income accounting has lagged so far behind its theory that we have little idea of what the facts have been. It is possible that time trends in such commonly used socio-economic indicators as GNP per head, life expectancy at birth, infant survival rate and literacy give us a singularly misleading picture of movements of the true standard of living.

To state the matter succinctly, current-day estimates of socio-economic indicators are biased because the accounting value of changes in the stocks of natural capital are not taken into account. Because their accounting prices are not available, environmental resources on-site are frequently regarded as having no value. This amounts to regarding the depreciation of natural capital as being of no consequence. But as these resources are scarce goods, their accounting prices are positive. So, if they depreciate, there is a social loss. It means that profits attributed to economic activities which degrade the environment are frequently greater than the social profits they generate. Commercial rates of return on investment are higher than the true rates of return on investment. In short, resource-intensive projects appear to be better than they actually are. Wrong investment projects get chosen in both the private and public sectors. We may conclude that investment projects earning high rates of commercial return could well be contributing to a reduction in the social wealth of nations (Dasgupta and Mäler, 2000). It should come as no surprise then that installed technologies are often unfriendly towards the environment and, thereby, towards those whose lives depend directly on the local natural resource base. This is likely to be especially true in poor countries, where environmental legislation is usually neither strong nor effectively enforced. The installation of modern technology can harm the poorest in ways that are often not reflected in commercial costs.

The above account explains why 'modern technology' isn't necessarily 'appropriate technology' and why the poorest of the poor in poor countries have, when they have been permitted to, been known to protest against the installation of modern technology. The transfer of technology from advanced countries can be inappropriate even when that same body of technology is appropriate in the country of original adoption. This is because the structure of accounting prices, most especially that of the local natural resource base, varies from country to country. A project design which is socially profitable in one country may not be socially profitable in another. Our analysis helps explain why environmental groups in poor countries frequently appear to be backward looking, unearthing as they try to do on occasion traditional technologies for soil conservation, water management, and so forth (see, for example, Agarwal and Narain, 1996).

The extent to which inappropriate technology is adopted varies from case to case, and from country to country. But it can be substantial. In their work on the depreciation of natural resources in Costa Rica, Solorzano *et al*. (1991) estimated that in 1989 the depreciation of three resources – forests, soil and fisheries – amounted to about 10% of gross domestic product (GDP) and over one-third of gross capital accumulation.

So far I have talked about biases in the adoption of established technology and thus about biases in technology transfer. One can go further: the bias towards wrong technology extends to the prior stage of research and development. When environmental natural resources are underpriced (in the extreme, when they are not priced at all), there is little incentive on anyone’s part to develop technologies which would economize their use. So technological research and technological change are systematically directed against the environment. Often enough, environmental ‘cures’ are sought once it is perceived that past choices have been damaging to the environment, whereas ‘prevention’, or input reduction, would have been the better choice. To give an example, Chichilnisky and Heal (1998) compared the costs of restoring the ecological functioning of the Catskill Watershed ecosystem in New York State with the costs of replacing the natural water purification and filtration services the ecosystem has provided in the past by building a water purification plant costing US$ 8 billion. They have shown the overwhelming economic advantages of preservation over construction: independent of the other services the Catskill watershed provides, and ignoring the annual running costs of US$ 300 million for a filtration plant, the capital costs alone showed a more than sixfold advantage for investing in the natural capital base. Their investigation offers a rough estimate of the social worth (or accounting price) of the watershed itself.

Social norms and the research environment

If philosophers and sociologists of science in earlier days used to study mostly the epistemological problems driving scientific research, today they also study the institutions within which research is conducted. The structure of incentives in science and technology, viewed as social institutions, affects the agenda of research and also research practice. In this lecture I have suggested that the disquiet being expressed at this Conference and that voiced at the International Forum of Young Scientists have two sources, one bearing on both science and technology, the other on science alone. The first is reflected in the feeling that modern technology is environmentally rapacious. I have offered a reason why the feeling may be a reasonable one: the environment is underpriced, so scientific and technological research is not directed at economizing on the environment. The way forward would be for scientists and technologists to be more engaged in collaborative work with social scientists, even at the design stage of the research endeavour.

The second source of the disquiet stems from problems faced by science, which is increasingly under threat from technology. The threat has arisen because science, unlike technology, requires for its survival a strong system of self-regulation and public support. Now public support is a public good. When the public begin to regard science as being less valuable than before, science contracts. Something like this may well have happened among the public in the North in recent years. Since self-regulation, too, is a public good, it would be undersupplied unless, collectively, scientists were willing to put in the time and effort to make the institution work. I have tried to illustrate the way the quality of research suffers if there isn’t a strong self-regulatory system at work by discussing three examples from economics, the subject I know best. Academies are of the utmost importance at this juncture. If my analysis is correct, part of the disquiet being voiced at this Conference is in effect an expression of disappointment that the structure of authority within the institution of science has weakened in recent decades.

Notes

1. See *Statement of Young Scientists*, Forum III, p. 448.
2. A ‘public good’ is something that is jointly usable.
3. See Dasgupta and David (1987, 1994) and Stephan (1996). I am aware that patents are a device by which knowledge can be privatized even while publicly available (e.g. the patenting of genes). But as patents were historically not granted to the discovery of ‘facts of nature’, secrecy had to be practised in order to prevent rivals from building round patents.
4. Daily (1997) contains an account of such services and Dasgupta (1996) an account of why we should not expect the use of many such services to be subject to market discipline.

5. In fact, a general finding from studies on the management of common property systems is that entitlements to products of the commons is, and was, almost always based on private holdings. See McKean (1992) and Ostrom and Gardner (1993).
6. See Reed (1992) for an empirical investigation in three poor countries of some of the effects of structural adjustment programmes on resource bases.
7. As I am wholly inexpert on the matter, I am not offering even a sketch of the kinds of argument that can be advanced to show that the reforms that were urged upon Russia in the early 1990s suffered from a lack of acknowledgement of the role that governance plays in the operation of markets. In an illuminating body of work, Richard Rose (see, for example, Rose, 1999) has been investigating the way social networks there have entered spheres of activity they would not have if citizens were to have enjoyed reliable governance.
8. This example has been added to the revised version of the lecture.
9. There are other types of institutional failure responsible for environmental degradation (e.g. government failure; Dasgupta, 1996), but here I concentrate on market failure.

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FORUM II KEYNOTE SPEECH

Science: the gender issue

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On behalf of the Third World Organization for Women in Science (TWOWS), I am honoured to address this plenary session of the World Conference on Science on the topic Science: the Gender Issue.

I cannot presume to think that the ideas I shall present here are original; they have been presented many times before in many forums. What I will try to do will be to highlight the tremendous developments in science during the 20th century and their impact on society. I will also briefly analyse the social status and roles of women and conclude that these have influenced the extent of women's participation in every sector of human activity, including science.

The world is witnessing the close of a century of tremendous achievements in science and of a proliferation of technologies which have had a far-reaching impact on every aspect of human life. There have been numerous beneficial effects of science and technology ranging from the large-scale industrialization of many countries to the Green Revolution; from the eradication of scourges that for centuries had decimated whole populations in different parts of world to the acquisition of greater understanding of life's processes and the state of the physical environment. Advances in the medical sciences still deserve special mention in spite of the current tragedy of HIV/AIDS and the resurgence of tuberculosis which continue to pose a daunting challenge to science and technology.

There have also sadly been many detrimental effects accruing from the use of science and its products. Some of these have been the manufacture and use of lethal weapons of war which continue to threaten the very existence of the human race, in spite of numerous international conventions on disarmament; the manufacture of mind-changing drugs which, while providing lucrative trade to drug barons, has enormous implications for the quality of life especially among youth; and environmental degradation, which is related to a considerable extent to industrialization and other aspects of development.

On the other hand, the emergence of information and communication technologies has contributed immensely to global communication and information dissemination, linking individuals, countries and regions in a manner never before possible. All the indications are that the 21st century will see even greater global interdependence but this will demand that countries develop or consolidate their capacities for scientific research and technological innovation. The consequences will be the widening of the gap between the developed and developing countries based on their state of scientific and technological advancement with almost complete marginalization of the least-developed countries with poor capacities in these areas.

The area of new technologies is indeed of particular interest in the context of gender equality in science and technology. Can this area accord women a special niche in which they can be fully engaged in education, scientific research and development? While it is predicted that the 21st century will be shaped by science and technology, issues such as respect for human rights, gender equity and environmental conservation promise a future that will be more sensitive to human concerns, a factor that will mitigate the strong and overpowering demands of the scientific enterprise.

What is noteworthy, however, is the dizzying speed at which scientific and technological changes occur, leaving little time for reflection about their effects on society and on the appropriateness for human development of the paradigms that govern the practice of science. Ethical issues which are linked to scientific research and development often surface but soon become submerged in the flurry of activities which are undertaken to maintain the fast pace of research and innovation. It is also noteworthy that, in many parts of the developing world, the tremendous scientific achievements which are being hailed as unprecedented in human history have hardly touched the lives of a large portion of society that still faces debilitating poverty and deprivation, in stark contrast to societies in the developed world.

In the context of the topic under discussion it is important to pause and take note of some of the features of science and technology which are relevant to issues of gender and to the overall theme of science and society. These features are:

- The Western model which leads scientific development in all parts of the world is based on a Western world-view of science, emphasizing that science is a human activity which is heavily influenced by cultural norms and values, contemporary thought and philosophy.

- Science and technology, which have become major influences of our times, remain male domains. Could the under-representation of women, especially at the leadership level of science, be attributed to the overall social status of women which has created stereotypes for the role of women in society?

At this stage, I will present a brief background of the evolution of the complex social perceptions of women's roles as an appropriate preface to suggestions on how to address gender equity in science and technology.

Women in society

The historical development of civilizations in Africa, Asia, Arabia and Europe has common features with respect to the social status and roles of women. This is evident in the diverse cultures that richly endow the world and is nowhere more clearly stated than in the great world religions and mythologies. In almost all cultures there is an underlying assumption which is very ably expressed by Lerner (1993):

'Men and women are essentially different creatures, not only in their biological equipment, but in their needs, capacities and functions. Men and women also differ in the way they were created and in the social functions assigned to them by God.'

Whether or not you believe in the existence of God, the supreme being portrayed in different ways in different religions, the divine delineation of male and female functions permeates social organization throughout the world and, more importantly, presents women as inferior to men, physically and mentally. The biblical account of creation depicts Adam as being created in the perfect image of God while Eve, the woman extracted from his rib cage, is like a cutting from the perfect stem. It should be noted that Eve was extracted from Adam's chest and not from his brain, an act that might have given women a chance to claim intellectual equality with men.

The belief in the superiority of men over women has persisted for centuries even as societies evolved, adopting new ideas and attitudes towards all aspects of human activity. Wemple (1981) traces the factors which have influenced the situation of women in Western society from the 5th century and in her treatise points out that women were expected to live under the authority of their fathers, if single, and husbands, if married, thus according them the status of a minor throughout their lives. This is still prevalent in many societies, especially in the developing world. The outcome of this social order has been differential preparation of men and women to assume their roles in society and their socialization to accept these roles as necessary for social stability and cohesion. This differential preparation even affected curricula in formal education, where, for decades, girls have been channelled to domestic sciences and boys to subjects such as woodwork and metalwork in anticipation of their masculine roles (Plateau, 1995).

This gender-based approach to education persists to the present day in many parts of the world where curricula for girls de-emphasize the physical sciences. Although this has changed significantly in many countries, it has been pointed out that the approach to teaching science has little regard for the preparation of girls for careers in science (Plateau, 1995). This is unfortunate because science and technology have been termed 'engines of social and economic change' so it is essential that women be well grounded in these areas in order to enhance their roles as mothers, social educators and transmitters of ideas from generation to generation. The renowned African scholar Ali Mazrui refers to the promotion of women's participation in science as the 'androgenization' of science, and sees this as a crucial strategy for giving science and technology both male and female characteristics after generations of masculine bias. He adds that, when more women become involved in science, the culture of science will not only influence their lives but also the lives of their children and of society in general. This, he says, is an 'important prediction for true sustainable development' (Mazrui, 1999).

The contribution of the United Nations to the promotion of women in development must be acknowledged. The United Nations has spearheaded a global debate on the role of women for decades, the latest being the United Nations Conference on Women held in Beijing, China, in 1995. There now exists a worldwide awareness of gender issues which nevertheless remain a vital concern for humanity.

In examining the topic before us, therefore, it is crucial to keep in full view the strong social and cultural traditions which have laid a foundation for the determination of women's status in society. This awareness must form the frame on which strategies to achieve gender equality in science and technology must be formulated. Some questions have been asked: Is it realistic to expect gender equality in the light of history and the socio-cultural norms which continue to haunt the minds of both men and women even on the eve of the 21st century? Has the social hierarchy which places men above women influenced potential involvement of women in science? Since science as currently practised leans heavily on

Western social values and norms, could the situation of women in science have been different if scientific development had not been so closely aligned with Western norms and values? Why is it important that women be afforded equal opportunities to practise science alongside men? Is the scientific enterprise poorer without the full involvement of women scientists as an essential human resource? Could greater participation of women in science influence the international scientific agenda towards scientific applications that address basic human necessities (Makhubu, 1993)?

I will very briefly present relevant aspects of the history of science.

Brief history of science

A well-documented account by Wertheim on the history of physics is rich with illustrations of the masculine character of science and the almost total marginalization of women for nearly 2 000 years of important scientific research on the origin of the universe (Wertheim, 1997). She recalls the work of physicists in which a strong link between physics and religion is reflected, when distinguished scientists grappled with theories to explain the existence or possible existence of a creator of the universe. From Pythagoras, through Isaac Newton to Einstein and Abdus Salam, the science-religion nexus is clearly evident and is said by many to be one of the strongest inhibitors of women's progress in science.

Wertheim goes on to assert that this religion-science nexus rests on the old belief that women are 'cast on the side of the material, the bodily and the earthly', while men have been 'cast on the side of the spiritual, the intellectual and heavenly'. Femaleness is associated with the 'physical, the personal and the domestic' and maleness with 'psychic transcendence' and hence more inclined towards the mathematically based sciences. She concludes that it is not surprising that, when women did finally enter the sciences, they selected the life sciences while the mathematically based sciences, especially physics, remain a male domain to the present day (Wertheim, 1997).

This observation is illustrated by data obtained from graduation lists in America in 1991 and 1992. The majority of women graduating from the sciences came from the biological life sciences and the social sciences. This observation compares well with the disciplinary choices of members of TWOWS where women scientists of the Third World show a definite inclination towards the life sciences. Similarly, in the TWOWS African membership the majority are found in the biological, medical and veterinary sciences. Further illustration of this trend is shown in data obtained in India and Venezuela.

This inclination towards the life sciences is also indicated by women Nobel laureates. Of the Nobel prizes won by nine women since 1901, two are in Physics, three in Chemistry and five in Medicine, clearly in favour of the life sciences.

While in countries like Venezuela, the gap in numbers between men and women in science is not large, an area of general concern is the paucity of women at the scientific leadership level of academic and research institutions where policies that guide the practice of science are formulated.

Data obtained from selected universities in Africa and the Middle East show that the percentage of women at the professorial level is very small.

In order to get to the top, many of the pioneer women scientists had to overcome numerous hurdles, ranging from outright rejection in scientific institutions to open discrimination in appointments. The male scientific communities could not accept them as equal partners and colleagues who could contribute to the advancement of science as well as men. They were seen as potential liabilities who could withdraw any time from teaching, research and other scientific activities in order to get married and raise children. For many women the scientific career has meant a choice between marriage, motherhood and science. Should women have to face this choice? Can women be wives, mothers and scientists at the same time?

Women: leading from strength

From the data presented, there can be no doubt that women show definite strength in the life sciences in almost all parts of the world. This female inclination towards the life sciences must be considered a strength in the context of many developing country concerns. The use of natural resources, health, food production, nutrition and education are all areas in which women from all walks of life have been intimately engaged over centuries. Can this modern scientific strength be combined with the traditional involvement and accumulated wisdom to produce a plan of action in which women can offer unique leadership in science for the benefit of humankind, focusing on the use of science and technology to alleviate human suffering, poverty and deprivation (Makhubu, 1997)? Can women lead from strength? How is this feminine strength represented in the new and emerging technologies, especially biotechnology, which are shaping the future of humankind? These questions were posed in a symposium entitled Science in Africa, Women Leading from Strength, organized by the American Association for the Advancement of Science (AAAS) in 1993. Women, the traditional educators and transmitters of cultural values, must be in the vanguard of the integration of science and culture, of science education, of research and development policy-making and in the creation of a vision for the 21st century in which human needs will form the focus for scientific and technological development endeavours.

Proposed interventions

Ladies and gentlemen, the preceding discussion has attempted to highlight socio-cultural reasons for gender imbalances and presented statistics which indicate that, while progress has been made in training women in the sciences, much more remains to be done. It has also highlighted what may be perceived as women's natural inclination, the life sciences – a strength to enable women to contribute to the use of science for the benefit of humankind.

I now wish to examine a number of interventions designed to address gender imbalances; they are examined on the basis of target groups. The examples which will be mentioned are taken from the developing world, in particular the continent of Africa.

The scientific community

For any cause to succeed, there must be strong advocates who are driven by conviction to advance well-reasoned arguments for change. These must be men and women scientists who are convinced that paradigm shifts are necessary in order to enable women to contribute to scientific and technological development. Such shifts must first and foremost acknowledge that women perform social roles which are fundamental to human development and yet have a potential to use these roles to infuse a humane character into science and technology, making them more responsive to human needs. Collaboration between natural and social scientists is strongly advocated in order to facilitate addressing the social issues relevant to the use of science.

There are several women's organizations which could take a lead in this respect, avoiding at all cost creating forums for women to talk to themselves. TWOWS has a membership of nearly 2 000 women scientists from all parts of the developing world. These women, who have diverse experiences functioning as women in their cultural settings, could provide discussion papers to address the questions posed above. But TWOWS must be joined by organizations such as the Third World Academy of Sciences, UNESCO, ICSU and others representing different parts of the world, men and women working together to provide ideas on how women's potential could be developed and tapped without removing them from their social roles which are so fundamental to human existence. A shift in the paradigms governing the practice of science is necessary to promote greater involvement of women in science.

Confronting gender stereotyping in education

One of the greatest obstacles to women's progress in many parts of the world is the lack of adequate opportunities for education. It is reported that at the present moment one out of three women in the world is illiterate, fewer girls attend school than boys, etc. It has also been established that, within the classroom, especially during science lessons, boys receive more attention from the teachers and are offered more opportunities for hands-on practical work, while girls are almost ignored, reinforcing the stereotype that science is a boy's subject. Textbooks often depict boys as the key figures in science and technology and, although change is taking place in this area, the whole exercise needs much more attention.

Many interventions have been suggested to combat the stereotyping of the science curriculum. The Female Education in Mathematics and Science in Africa (FEMSA) initiative is a project of the Association for the Development of Education in Africa (ADEA) Working Group on Female Participation (WGFP), of which the Rockefeller Foundation is the lead agency. The Forum for African Women Educationalists (FAWE), based in Nairobi, Kenya, is hosting FEMSA, which is spreading throughout the African continent.

The main goal of FEMSA is to promote the participation and performance of girls in science, mathematics and technology (SMT) subjects at primary and secondary schools by mounting in-class interventions during science and mathematics lessons. The interviews with male and female teachers and their students reveal well-entrenched social attitudes towards girls' study of science which must be addressed if girls are to have the confidence to study science. Similar programmes are organized in different parts of the world and all aim to address the problems of gender stereotyping in science and technology.

Building confidence in young girls to pursue scientific careers

Several countries have organized science clinics for girls where female high-school students have spent time in camps doing hands-on projects, interacting with well-known female scientists – their role models – and generally being inspired to believe in their capabilities to study science. Such clinics have been organized in Botswana and Ghana where the current holder of the UNESCO Chair in Science and Technology for Women in Africa, Professor Aba Andam of the University of Science and Technology, Kumasi, is concentrating on this activity.

This project has now been extended to several African countries in order to help teachers and students, curriculum designers, career guidance teachers and counsellors confront gender stereotyping in science and mathematics. This is another intervention that addresses the fundamental problem of lack of confidence to study science among girls.

These two interventions require persistence by the scientific community, both men and women, and should be viewed as long-term projects which are essential for confronting basic attitudes towards girls and women in science.

Promoting postgraduate training of women to PhD level

While it is noted that there are generally fewer women science undergraduates than men in many countries, it is evident that there are even fewer who proceed with postgraduate training to PhD level. One of the reasons advanced to explain this situation is the fact that many women get married and start raising families soon after obtaining a first degree. For many, especially in some developing countries where postgraduate training is undertaken abroad for stretches of three to five years, it proves very difficult to leave the family to pursue higher-level training. Female scientists may, once again, have to make a choice between family and career. Many choose the family in accordance with social expectations. One of the interventions offered by TWOWS, beginning in 1998, under the sponsorship of SAREC, involves giving grants to women MSc holders in sub-Saharan Africa to embark on sandwich-type PhDs at centres of excellence in the South. This type of programme should assist women to pursue higher degrees without parting them from their families for prolonged periods of time. This programme acknowledges that women have important roles to play as mothers and wives and need special support to develop as scientists and academics. The strengthening of postgraduate training in science and technology in the South is important in encouraging more women to pursue higher-level studies close to home.

Strengthening women's research output in universities and research institutions

In order to achieve upward mobility in universities and research institutions, a scientist has to produce a number of quality publications, for these are the determinants of promotion to higher ranks and leadership.

One of the interventions which has been proposed is the strengthening of research collaboration among women to create groups that can tackle sizeable research projects and can continue to work even if one member has been slowed down by family responsibilities. Thus, joint projects and joint publications are considered an important means of facilitating women's upward mobility under current practices, in scientific institutions and universities. A network of this kind called the Women in Science Network in Africa (WISTAN) has been formed by the UNESCO Chair holder at the University of Swaziland under the sponsorship of the Association of African Universities, UNESCO and the Rockefeller Foundation. Such networks could encourage women to form research support groups to enable them to research and publish regularly.

Promoting public understanding of science as an activity closely aligned with women's activities

The female inclination towards the live sciences has been said to reflect women's traditional roles as mothers, environmentalists and health workers. Although women perform these 'scientific activities' every day, they themselves and society at large still regard science as a male domain. A project by the UNESCO Chair in Swaziland, involving primary pupils and teachers, rural women and university lecturers in science, has selected 'water' as the theme for discussion and demonstration of the 'scientific' nature of women's work. Similar projects elsewhere, designed to highlight women as 'scientists' on a daily basis, are important for bringing science closer to society. They are also important in promoting the relationship between science and culture, especially in those developing countries where science and culture stand apart.

These interventions are suggested as a means of strengthening and building women's scientific capacities and also creating an international environment in which women will engage in scientific pursuits and still discharge their fundamental social responsibilities.

Conclusion

I conclude on a somewhat personal note. Throughout my academic training and subsequent experience in the world of science and university administration, three convictions have increasingly shaped my own paradigm:

- that women are well able to hold their own in the 'man's world' of science and technology, and that they have a unique dimension to lend to the scientific enterprise;
- that great potential is being lost by failure to encourage more women to enter the world of scientific exploration;

- that subsequent generations will judge us, the scientific community, on our ability to use science to benefit the poorest, most disadvantaged sectors of society.

These are crucial issues which we must address. We have to consider afresh the role of women in the scientific enterprise, to think it out again from the beginning. We must secure for women an entirely new value and significance and we cannot do that unless women themselves are allowed to have a say in determining what that value should be. Only when we listen to the opinions of the disadvantaged will we be able to serve the interests of humanity as a whole. An equitable partnership of men and women scientists can surely achieve that goal.

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FORUM II KEYNOTE SPEECH

A new social contract for science

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I add my thanks to the UNESCO and ICSU organizers for their respective roles in organizing this meeting and to our Hungarian hosts for their gracious and thoughtful preparations and arrangements.

This World Conference on Science is a remarkable event. Our presence here and our focus on the theme Science for the 21st Century: A New Commitment should send a strong message to other scientists and to the world. Our actions here should declare that we are concerned about the state of the world. Our dialogue should demonstrate that we are re-examining our social responsibilities. Our conclusions should reflect that we are rededicating ourselves to help address the most urgent problems of society. In short, we are in the early stages of forging a new social contract, one in which we pledge to focus our energies for the betterment of humanity.

This meeting builds upon multiple earlier efforts around the world. Like rivulets converging into streams, streams in turn joining to form rivers and rivers merging with other powerful rivers, our energy and momentum are building. Our challenge is to ensure that this river is life sustaining, that it brings rich benefits to the sea of humanity.

My remarks today focus on the rationale for and challenges associated with formulating a new social contract. My points will be that:

- The world in which we live and do our science has changed dramatically. I will focus specifically on ways in which oceans are changing.
- New commitments to direct our scientific efforts to the most important problems are in order.

My premise is that the broad sweep of environmental changes that have occurred in the last century have much more serious consequences for human well-being and prosperity than is generally recognized. Moreover, scientific understanding is urgently needed to inform the decisions of individuals and institutions. The shift to a pathway leading towards a more sustainable and just world requires nothing less than our full commitment.

You are all quite familiar with the major drivers of environmental change – the explosive growth of the human population, the unsustainable rate at which we are using resources and generating wastes, the increases in poverty and inequity within and among all nations and the ignorance, arrogance, despair and denial which exacerbate the other drivers.

These complex drivers of change are collectively rendering our planet a far different place than ever before. We are terrestrial creatures so it is not surprising that our immediate focus is on the land around us. Much has been said about global-scale terrestrial changes. What hidden changes are occurring in the 70% of the planet covered by the oceans? Some 40% of the world's population lives within 100km of the ocean and the percentage is growing, for example at a rate greater than 1% per year in the USA. What is happening on our doorstep?

I invite you to take a virtual field trip with me now to the salty and wet realm that is the ocean. We will glimpse some of the ways in which the seas are changing. I will draw your attention to seven global-scale indicators of change that serve to encapsulate the status of oceans. These indicators were chosen because good, quantitative data exist to ground our assessment. These indicators enable us to move beyond assertions and focus on changes we can document with confidence.

The first three of the seven indicators reflect the consequences of ocean-based activities.

1. Two-thirds of the major marine fisheries are fully exploited, over-exploited or depleted. Even these dire numbers do not reveal the full extent to which we have unwittingly depleted ocean resources. By-catch, the unreported accidental catch that is most often tossed back overboard, dead, represents around 30 million tonnes annually, about one-third again as much as the total landed biomass.
2. Habitat alteration is as pervasive in the ocean as it is on land. Mangroves are one marine habitat where figures indicating the extent of change are available. Scientists have documented that 50% of mangroves have been destroyed in the last few decades, due to a combination of coastal development, agriculture and construction of shrimp aquaculture ponds.
3. More than 3 000 species are estimated to be in transit in the ballast water of ocean-going vessels each day. Native

species are taken into ballast tanks in one port then often discharged far across the world – aliens introduced into a new habitat. Rates of successful invasions are increasing. Zebra mussels introduced from Europe are displacing native species and causing millions of dollars of damage in North America. The comb jelly *Mnemiopsis*, introduced into the Black Sea (the terminus of the Danube River – just outside our door), has contributed significantly to the demise of Black Sea fisheries.

The threat from introduced species – both on land and in the oceans – is probably far greater than the threat of genetically modified organisms.

The other four indicators of changes in oceans are due to land-based activities.

4. Human activities have increased the carbon dioxide concentration in the atmosphere by 30% since the beginning of the Industrial Revolution. Significant progress has been made in understanding some of the likely consequences of the increases in this and other greenhouse gases. We've already witnessed a rise in sea level of 15-25cm in the last century, with an expected additional increase of 15-95cm by 2100. Corals are reported to be bleaching with increased frequency around the world, perhaps due to warmer waters and also possibly due to increased UV-B radiation.
5. Humanity now utilizes more than half the available surface fresh water, significantly reducing the water flow required by anadromous species such as salmon and also impairing the functioning of wetlands and estuaries.
6. Between one-third and one-half of the entire land surface of the planet has been transformed by human action. A wide variety of these transformations affect oceans directly and indirectly. For example, in the Pacific Northwest of the USA, deforestation, livestock grazing, agriculture and urbanization have all contributed significantly to the demise of a number of species of salmon.
7. Human activities have now more than doubled the amount of nitrogen fixed annually. Much of this fixed nitrogen is in the form of fertilizers. Unfortunately, significant amounts of fertilizer are not used by crops but are washed away into streams, rivers and eventually into coastal waters. Excess nitrogen and other nutrients may be responsible for some of the global increases in frequency, duration and extent of harmful algal blooms, including some red tides, with often serious consequences for human health.

A separate consequence of excess nutrients is the appearance of zones of hypoxia and anoxia, i.e. low to no oxygen, the so-called 'dead zones'. There are now some 50 persistent dead zones around the world, most of which have appeared during the last 50 years. The largest in the Western Hemisphere is in the Gulf of Mexico, at the mouth of the Mississippi River, and measures approximately 16 000km.

These seven indicators of change – in fisheries, habitat destruction, invasive species, carbon dioxide, water, land transformation and the nitrogen cycle – do not represent all the changes affecting the oceans. Indeed they are only those for which we have some credible quantitative documentation.

I focus on these changes in oceans as representative of planet-wide changes. One obvious conclusion from this litany is that we now live on a human-dominated planet. The environmental changes of the present century are significantly different from any others. Changes are happening over larger scales, at faster rates and many are new.

These changes have immediate and long-term consequences for people – to a much greater degree than is generally appreciated. If you ask most people how they depend upon nature, most will readily point to the goods we obtain – food, fibre, genes, medicine. Few are aware of the extent to which humans also derive essential ecosystem services from natural ecological systems. These services range from the provision of fertile soil to the purification of water, from partial regulation of climate to flood control.

Taken together, these goods and services provide the life-support systems for the planet. When ecological systems are transformed or degraded or when species are eliminated from them, the functioning of the ecosystems is often disrupted and the delivery of the services is impaired.

For example, forested watersheds around the world provide water purification and filtration and thus clean drinking water for people. In New York City, the quality of drinking water recently dropped below EPA drinking water standards due to a combination of urbanization, agriculture and industrial practices in the Catskill Watershed. An analysis by Heal and Chichilnisky sheds light on just how valuable this ecosystem service is. They calculated that the cost of buying and restoring the watershed, to restore its ability to provide the ecosystem service of water purification and filtration, would be US$ 1 billion, no small sum, but considerably less than the US$ 6-8 billion cost of building a water filtration and purification plant. Clearly this and other ecosystem services are valuable and worth conserving.

The broad sweep of ongoing environmental changes led E.O. Wilson to suggest that we are on the verge of entering the century of the environment. I further suggest that we are also in the process of redefining what 'environment' means.

Specifically, we are redefining human health, social justice, the economy and national security as environmental issues – as we begin to appreciate the full extent to which each of these is linked to the functioning of ecological systems. The context in which we do science has changed.

Thus, as we enter the century of the environment, humanity is urgently in need of information, understanding and guidance about environmental changes, human health, social justice, economy and national security. Our knowledge in these areas is woefully inadequate but, with a serious effort, significant advances could be made. At the same time, much knowledge is in hand, but is not integrated, synthesized or communicated – not to the public nor to policy-makers.

We often talk about the role of science in making discoveries that lead to new cures or new technologies to improve our lives or stimulate our economies. There is another equally vital role of science – to inform our understanding and decisions. This, then, is the basis for a new social contract with science. The world around us has changed dramatically, yet our scientific enterprise is not providing the full spectrum of guidance we would wish to make more enlightened decisions. Note that I do not suggest that scientific information should dictate action, rather that it should inform action.

Better information is urgently needed about how our environment is changing and how we can better manage our activities. Physical, chemical, biological and social sciences, engineering, and technology are all relevant and necessary disciplines. Moreover, interdisciplinary approaches are essential.

We are fortunate to have a number of models of successful interdisciplinary scientific assessments which demonstrate the feasibility and usefulness of synthesizing knowledge to inform policy: the ozone assessments, the Intergovernmental Panel on Climate Change, the Global Biodiversity Assessment and, most recently, the interlinkages assessment (Protecting Our Planet – Securing Our Future, United Nations Environment Programme (UNEP), National Aeronautics and Space Administration (NASA) and the World Bank).

Two emerging programmes represent much-needed efforts and would go a long way towards helping provide some of the additional necessary information and understanding. The Millennium Assessment of the World's Ecosystems and the International Program on Ecosystem Change (IPEC) propose to promote research and synthesis of information on ecosystem states and change. The underlying assumption of these two complementary efforts is that the long-term impacts and human ecosystem domination are the most intellectually challenging and socially important issues that have ever faced science.

Acquiring this understanding will require a substantive, interdisciplinary effort, for example valuing ecosystem services and using the power of markets to conserve essential services. An international mechanism is needed to assess the status of Earth's ecosystems, develop scenarios for future changes in the supply of ecosystem goods and services and predict responses to potential management strategies.

These programmes would be only two of many elements of a new social contract – one in which the most pressing problems are addressed, one in which knowledge obtained from research is readily communicated and applied and one in which good judgement and wisdom are guiding principles. We need parallel efforts to pursue new knowledge and to make better use of information in hand.

The future is highly uncertain – it is highly probable that the changes already set in motion will result in increasing rates of change, greater uncertainty and surprises. These complex environmental and social systems are highly non-linear. Specific predictions are difficult.

In summary, during the last century we have learned new lessons about the environment – specifically that limits are real, now is different, rates of change are critical, goods and services are the life-support systems of the planet and that uncertainty in complex systems warrants precaution. Caution is warranted especially where changes are irreversible (such as loss of biodiversity).

A new social contract reflects the recognition that the life-support systems of the planet are fragile and must be better understood and managed. All countries – developed and developing – will benefit from better information about how our environment is changing.

A new commitment to the discovery, integration, synthesis, communication and application of this new knowledge would be a fitting outcome of this World Conference on Science. Our goal is nothing less than a sustainable biosphere that is ecologically sound, economically strong, socially just and politically supported. This commitment must be made by individuals as well as by countries. This Conference should enable those commitments.

FORUM II KEYNOTE SPEECH

Science for future generations

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It is a pleasure and an honour for me to take this opportunity to extend my gratitude to UNESCO and ICSU for inviting me to make a keynote speech to this important World Conference on Science. My presentation on Science for Future Generations is mainly concerned with the sustainable development of science and the relationship between present and future generations.

In this presentation, I would like to address the following issues for debate and discussion: responsibilities of the present generation towards future generations, the role of youngsters in science for development, the contribution of science to development and how to develop science in the context of sustainable development. I would also like to stress the importance of collaboration between scientists and decision-makers to share responsibility for creating scientifically sound long-term risk assessment and management, along with improved long-term scientific prediction and incentives for innovative thinking.

Responsibilities of the present generation

Social development in the coming millennium, including improvement of living standards, rational utilization of resources, preservation of ecological diversity and world peace, social security and stability, environmental improvement, extension of living space, sustainable development, fulfilment of desire for new knowledge, etc., will largely depend on the advancement of science. In such circumstances, the present generation has a responsibility to develop science for sustainable development, impart scientific knowledge to future generations, advise youngsters about creative activities and put youngsters on the right track for the future leadership of scientific development.

To grasp laws and principles of contemporary science and to forecast the future development of science

The traditional boundary of scientific disciplines is becoming more vague than ever before and the interface between disciplines is becoming a frontier for scientific breakthrough. Modern science is characterized by complexity, multidisciplinary interplay and diversity. Complexity means that the human social system, global economic system, ecosystem, human body, brain and neural system, earth system and other systems in modern science deal with multidimensional, multi-layered, and large-scale complex systems. Objects of scientific research, theory, methodology and application objectives are varied and diversified. No single discipline can solve these complicated problems. Thus, multidisciplinary and interdisciplinary efforts are needed. Meanwhile, with the rapid development of information and communication technology, the creation, dissemination, transfer and application of scientific knowledge are much faster than ever before. Scientific development is also promoted by global competition and collaboration.

It is the responsibility of the present generation to forecast the trend for science development and to lead future generations in the right direction. There will be greater achievements in physical science, life science, information and communication science and geoscience. Natural science and social science will be combined more closely or integrated to provide solutions to problems presenting uncertainty. Mathematics is still the basis of natural science, technology, engineering, economics and management science. The research focus of physical science will be on physical elements and their interactions within a complex system under harsh spatial and temporal conditions, creating new materials, energy and green technology. Breakthroughs in life science based on molecular biology will bring about revolutionary achievements in agriculture, medicine and human health. Extensive applications of demand-driven information science will bring big changes in social structure, lifestyle and modes of production. Advances in brain and cognitive science, psychology and behavioural science will give rise to a revolution in human education, information feedback and social development. Development of universe science will provide new knowledge for recognizing the origin and evolution of the universe. Geoscience will become more comprehensive and focus on exploring an optimum approach for rational utilization of resources, preservation of ecology and enhancement of environmental quality.

The present generation has a responsibility to establish a sound viewpoint of scientific social value, and to apply science in the promotion of social and economic development. Science provides us with the latest thoughts and instruments for recognizing the complicated processes of nature and human society. Scientific discovery is still the foundation of technological development and revolution. Science presents new means for peaceful coexistence between man and nature, and between different peoples. Scientific knowledge, methodology and evidence are used to enhance social civilization, legislature and decision-making. Advancement in science is also the basis for the eradication of poverty and inequity, improvement in human civilization and common development and improvement of the people's quality of life.

To create a sound social atmosphere for science development, which is especially important for developing countries

The physical conditions that the present generation can provide for scientific research include:

- establishing and enforcing legislature and long-term policies for scientific development based on specific national or international conditions;
- attracting and supporting talented people, providing them with necessary funding, equipment, data and communication networks, and international and domestic academic cooperation opportunities;
- setting up a rational institutional system for scientific research and development;
- maintaining disciplinary diversity and multidisciplinary partnership;
- forming lots of innovative centres of excellence for scientific research and advanced technology development.

The present society can create a good cultural atmosphere and social environment of academic freedom, respect for talent and knowledge, belief in science and inspiration for creativity.

The present generation can provide a sound basis for science education, maintain a high level of science popularization and strengthen international collaboration in scientific exploration.

To impart scientific knowledge, spirit and ethics to future generations

Another important responsibility incumbent on the present generation is to impart scientific knowledge, spirit and ethics with impartial, accurate language to future generations. The present generation should be geared towards making future generations understand the scientific laws and principles of past development, letting them know how to carry out scientific research and how to make scientific discoveries, training them in skills for creative thinking and developing their scientific spirit and scientific ethics.

Schooling is and will be the fundamental part of science education. To spread scientific knowledge and strengthen the innovation capability of youngsters, the emphasis of education should be on developing their interest, curiosity, creativity and social responsibility. Putting the latest scientific laws and principles into school curricula should be the first priority for the spread of knowledge. In so doing, both education authorities and faculty members have to work together closely to implement innovative approaches to curriculum reform, focusing on both contents and methods. Key factors are to make a quick response to the latest scientific developments and make a corresponding change and improvement in curricula through collaboration with scientific research institutions; to put in every course inquiry, the processes of science and the excitement of cutting-edge research; to devise and apply pedagogy that develops skills for creative thinking, learning-by-doing, communication and teamwork; to develop interdisciplinary and multidisciplinary partnerships and collaborations for illustrating scientific phenomena; and to develop scientific morality, ethics, and social value.

Contemporary scientists should focus not only on our own research but also on introducing scientific achievements to a larger audience than the scientific community. We should devote some of our energy to writing extensive reading materials. Extensive reading materials on scientific development should be written in simple, humorous and colloquial daily language. The importance of popularizing scientific knowledge among ordinary people has long been ignored by the scientific community. It should be recognized and emphasized in this World Conference on Science that scientists must take responsibility for improving the scientific quality of people.

With the rapid development of information and telecommunication technology, the Internet and the mass media, including radio, television and the compact disc, can be used as effective media for transmitting scientific knowledge to the audience that cannot be reached by means of traditional media.

Role of youngsters in scientific development

The future lies in the hands of youngsters. Youngsters have an important role to play in receiving education, participating in scientific research and taking the leadership in scientific development.

Youngsters have the right to be educated without discrimination on the grounds of race, religion, age or sex. In China, all young people have to receive a nine-year compulsory education from primary school to middle school. After graduation from the middle school, some youngsters go on to college through comparatively fair entrance examinations or go on to further studies in vocational school. Those who are able to receive a formal education have the opportunity to access scientific knowledge and the latest scientific information through teachers and other formal channels of learning such as scientific journals, magazines and information networks.

Students should change their passive ways of learning for interactive ways of teaching and learning. They should develop their curiosity and interest in science, devise possible facilities and do laboratory tests, and give feedback to teachers enunciating their feelings in order to improve curricula. Given the present development status, many youngsters may not have the opportunity to receive a higher education. In this case, they have to find other ways of expanding their scientific knowledge; for example, they can go to evening classes, take up correspondence school, television or radio school or even short-term training courses and workshops. It is important for us to create favourable conditions for the arrival of the Era of Lifelong Learning.

In research-oriented university or graduate school, students are provided with opportunities to participate in research projects. Through participation in the research process, students can understand the whole process of scientific discovery. They learn how to identify scientific problems, to carry out literature reviews, to make preparations for scientific experiments, to observe different scientific phenomena, to formulate equations for variables, to analyse experimental results, to make trade-offs among the results and to present scientific laws or principles. As part of a research team, students learn teamwork and how to deal with scientists, engineers, technicians and workers with different academic, ethnic, cultural or even national backgrounds. Present and future scientific work needs close cooperation among all people concerned, including South-South and South-North cooperation.

Youngsters will eventually replace present scientists as the future leaders in scientific development. Leadership from bottom to top in scientific institutions will gradually be given to the youngsters. For a young scientist to be a leader, he/she should first have the ability to conduct independent research, be capable of identifying problems, developing proposals, getting support from funding agencies, making experiments and field tests, writing research reports and making presentations. From then on, the young scientist must learn how to lead a research team, lead a laboratory and to take a leadership role in strategic development of scientific programmes or institutions. To be future leaders, the young scientists should be able to take responsibility for making strategic plans for scientific development; identifying research and development (R&D) programmes at the scientific frontier and of significance; creating an attractive working environment for scientists; setting up a rational institutional system for creative thinking; being tolerant of different opinions and towards people with different backgrounds; having a strong and cooperative management team; seeking financial support through various possible channels; serving society; and maintaining collaborative linkages with the international community.

Science for sustainable development

Sustainable development means, as the World Commission on Environment and Development put it in its well-known report *Our Common Future*, ‘it meets the needs of the present without compromising the ability of future generations to meet their own needs’. The basic rule of sustainable development is to leave the same or an improved natural resource endowment as a bequest to the future.

Science has played a more and more important role in meeting the needs of the present. It was estimated that the scientific contribution to gross domestic product (GDP) was only about 10% in developed countries at the beginning of this century, while in the 1950s it was up to 40% and in the 1980s it reached 60-80%. In the developing countries and regions, science is a lifeline for people to get out of poverty and to enjoy the rights of survival and development. Many world-renowned economists believe that, in a long-term perspective, increases in capital and labour supply are not the major reason for sustainable economic growth. The real driving force behind sustainable economic growth is technical innovation based on scientific advancement.

Science can provide effective methods and instruments for decision-making on sustainable development, promote management, institutional reform and capacity-building. It can deepen the human understanding of natural laws and principles, help explore new natural resources, increase the efficiency of resource utilization and economic benefits, and provide effective technical measures for conservation of natural resources and preservation of the environment. As UNESCO mentioned in 1997, without science, sustainable development would not exist. In fact, science has played an important part in identifying and analysing problems related to the environment and development. It has played a large role in finding solutions, and taking actions, particularly in preventing ozone layer depletion, climate change, biodiversity reduction, water shortage and pollution, etc.

There is no doubt that science has made and will continue to make great contributions to sustainable development. But science may also do harm to sustainable development if not properly used. For example, modern industrial development has brought about great damages to the natural ecology and environment, nuclear technology has been frequently used against man and international peace, and pesticides have become a part of the food chain. For this reason, active measures should be taken to develop science in a sustainable way, that is, do less or zero harm to humans and the environment. In this context, the principles for developing scientific research, development and demonstration programmes should be to:

- incorporate consideration of objectives for sustainable development into strategic policy formulation, planning and priority-setting;
- establish effective communication channels between advisers, funders, performers and users concerned with the research, development and demonstration activities of sustainable development;
- encourage existing public sector funders and performers to cooperate in multidisciplinary and inter-institutional scientific activities that address intersectoral sustainable development issues;
- improve the consistency and comparability of environmental data and information systems;
- address sectoral and broad intersectoral sustainable development issues through scientific research, development and demonstration;
- ensure the peaceful utilization of scientific achievements through the concerted efforts and close cooperation of the international scientific community, in both developed and developing countries.

Collaboration of scientists and decision-makers in risk assessment and management

Risk can be seen as a combination of the probability of an accident occurring and of the damage it would cause. Because of the many uncertainties in the development of science, there may exist environmental, technological, social and economic risks that bring about losses to both human health and the natural environment. For example, use of fossil fuels – coal, oil and gas, where the most serious risk comes from greenhouse gas emissions and pollution to air and water – threatens the life-support system. Predatory exploitation of non-renewable resources causes the risk of depleting and exhausting the resource stock. This deprives coming generations of the right to share resources of the same quality. Use of modern means of transportation to convey chemicals may bear four major types of risks: the increase in greenhouse gas emissions, leakage of liquid or gasified materials, spread of toxic pollutants and risks of road accidents. Use of inflammable materials may cause fire or explosion. Nuclear energy is usually safe if carefully maintained, but potential dramatic accidents exist if the storage of radioactive waste is not solved and secured for the long time span of concern. Another concern is nuclear proliferation. Scientists in the developed countries should bear more responsibility for preventing these hazards.

Decision-makers at different levels have played a key role in risk evaluation and management. It is their responsibility to ensure that risks are evaluated on an objective basis and to indicate above which limit a risk is unacceptable (maximum allowable level) and below which limit a risk is negligible.

It is also the responsibility of decision-makers to protect society from catastrophic hazards that threaten the very existence of the community. But decision-makers cannot prevent or avoid risks on their own; they need the collaboration of scientists in providing accurate and timely information about risk attributes, location, normal solutions and action steps; identification of risk types and occurrence probability; assessment of risks and priority-setting for avoidance of different risks; and expert knowledge on risk prevention, emergency response and post-remediation measures.

Reducing either the probability or the consequences of a potential accident will result in reducing its risk. A preventative approach, based on scientific decision-making, improved maintenance, better training, ergonomic instruments and effective supervision, is the best approach for reducing risk. Therefore, scientists have a responsibility to collaborate with decision-makers on accident/disaster prevention as well as on the curative aspects of emergency response.

In terms of decision-making, risk and safety management should be introduced step by step at each of the four consecutive levels:

1. *National level:* formulation and adaptation of legislation and regulations that pursue set safety objectives with the general purpose of risk prevention and avoidance.

2. *Sectoral level:* adaptation of codes of good practice and guidelines for changes in a better direction.
3. *Company level:* adoption or adaptation of internal working procedures and technical measures.
4. *Public level:* monitoring and evaluation of public safety and operators' behaviour.

Scientific prediction

Scientific prediction is taken as a very important element of scientific innovation, which is one of the characteristics of the major science era. Prediction is used not only for preventing natural disasters and environmental changes, but also for making strategic plans for the future development of science and technology (S&T).

With the rapid development of S&T and the approach of the era of the knowledge-based economy, the great importance of scientific prediction for the development of human society has been clearly identified. But the dynamic development of S&T and the accelerating transformation of scientific achievements into technology and products have increased the difficulty, as well as urgency, of scientific prediction. The difficulty lies in the irreversibility of the events to be predicted and the multiformity of prediction criteria.

It is a big challenge to predict scientific development and its impact on ecological, economic and social progress. It will need a theoretical system for assessment, technical instruments and the participation of social scientists with advantageous ideology and social value, as well as close cooperation between natural science, engineering and social science. Scientific prediction usually includes the prediction of future scientific developments, pursuit of new scientific concepts, theory and methodology, and estimation of social, ecological and environmental changes induced by the transformation of 'science-engineering-economy-society' .

In terms of improved scientific prediction, the principles are: not only scientific laws but also ecological, economic and social demands should be taken into consideration; from a systematic point of view, all research areas should be included rather than some special areas; assessment of relative importance is given to different R&D projects for priority-setting; for the specific focus of scientific prediction, the anticipated objective-setting and the time for reaching success are key factors.

In the long term, the following should be taken into account for improved scientific prediction: breakthrough and innovation of scientific theory need to mobilize rational thoughts for discovery of basic laws behind facts; technical difficulties in solving present problems call for breakthroughs in theory; new theory may be derived from the facts which cannot be explained by traditional theory; new theory comes from interdisciplinary or multidisciplinary interaction or penetration; theoretical crisis emerges when traditional theory is challenged by the latest instruments and experiments, which is the eve of new theory; and the role of first-class scientists in taking the lead in theoretical innovation.

The knowledge-based expert system will take a more active role in long-term scientific prediction under uncertainty. Representative experts should cover all the fields of scientific research, development and demonstration; keep a balance between industry, academia and government; have as many outstanding, creative and active young scientists as possible; and include some futurists.

Incentives for innovative thinking

Innovative thinking is the origin of scientific development. The fundamental factors for scientific innovation include a favourable environment for the free exchange of ideas and information, the free flow of personnel, progress in economic and social conditions, availability of creative talents and sufficient funds and facilities to put creative ideas into practice.

To encourage innovative thinking, the first thing is to create a good atmosphere to encourage freedom to pursue new thoughts, free expression of new ideas and respect for knowledge and talent. Meanwhile, the intellectual property rights of creativity, such as new ideas, theory and methodology, should be well protected without infringement. The benefits, obligations and authority of innovators should be made into laws or regulations to provide a legal basis for creative activities.

The second is to set up a series of preferential policies for scientific innovation. These policies include: top priority for science education, research in basic and applied sciences, and application of scientific achievements; a comparatively stable and comfortable living and working environment for science workers; emphasis on bridging the gap between industry demand and academic supply, and encouraging scientists and engineers to work closely with industrial clients on solving technical problems; support for the development of scientific parks and high-tech zones; increasing the percentage of GDP given to financing of scientific research, development and demonstration programmes; and importance given to interdisciplinary and multidisciplinary collaboration, in particular cooperation between social and natural sciences.

The third is to establish some outreach centres of excellence mainly for conducting innovative projects. These centres are provided with sufficient human and capital resources, and required to enforce a performance-based management system. This includes having quality staff and equipment, rewarding staff for retention, tenure and promotion, equality, peer review of scientific achievements, funding for projects at the scientific frontier, frequent exchange of information and personnel with other centres of excellence in the world, introducing rational competition into the personnel management of R&D and adopting a tolerant attitude towards unqualified science workers.

Last but not least is enhancing the scientific awareness of ordinary people, including promoting their acceptance of innovative thinking, their tolerance towards unsuccessful innovators and their knowledge of innovation risks.

Conclusions

Science has played a more and more important role in meeting the needs of the present. There is no doubt that science will continue to make a great contribution to sustainable development. On the other hand, science may also bring damage to sustainable development if not properly used. Therefore, active measures should be taken to develop science in a sustainable way.

The present generation has multifaceted effects on science for future generations. Among them, the most important responsibilities for the present generation are to explore scientific laws and principles based on a deep understanding of the characteristics and functions of modern science, and to forecast the future development of science, on the one hand; and, on the other hand, to impart scientific knowledge with impartial language to future generations, to make future generations understand the scientific laws and principles of past development and to encourage them to take over social responsibility for developing scientific innovation capability, scientific minds and ethics.

Youngsters are the future of scientific development. They must first have the right to enjoy equal education, regardless of race, age or sex. They should be encouraged to develop their interest in science, participate in scientific research and eventually replace present scientists as the future leaders in science development.

There may be ecological, environmental, technical, social and economic risks in the scientific development process. In this case, scientists must share responsibilities with decision-makers at different levels to ensure that risks are evaluated on an objective basis, to protect social development against catastrophic hazards, wars, pollution and natural disasters that threaten the very existence of the community, and to use expert knowledge and ethics as well as rational thinking for risk prevention, emergency response and post-remediation.

Prediction of new scientific concepts and theories and unknown scientific phenomena are an indispensable part of scientific development. The knowledge-based expert system will take a more active role in long-term scientific prediction, which needs closer cooperation and collaboration among the scientific community of the world.

Innovative thinking is the origin of scientific development. In order to encourage innovative thinking, there should be a legal safeguard for the freedom of any individual to pursue new thoughts, free expression of original ideas, protection of intellectual property rights and respect for knowledge and talent. A series of favourable policies should be implemented and some outreach centres of excellence established for conducting innovation programmes. And the most important thing is to enhance the scientific awareness of the public to create a social and cultural atmosphere favourable to innovative thinking, which encourages academic equality and freedom of choice, exchange and collaboration with mutual respect and benefits.

Public perceptions of the connection between scientific research and social progress

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Studies conducted in the developed world, especially in the USA, show that the public generally perceives science as a beneficial force in human affairs. At the same time, those surveys show that public knowledge of the details of scientific knowledge is extremely low. Moreover, there is no simple relationship between knowledge and support; in some contexts, the more people know about science, the less they support it.

Some analyses of large quantitative surveys suggest that, although scientists perceive science as open investigation of nature, public perceptions of science have more practical images in mind; public perceptions view science like medicine, an applied field that uses knowledge of the natural world to yield specific practical benefits. Further complicating the issue is a separate line of research suggesting that public perceptions of science are highly contextual, with people making judgements about the relative trust to be placed in traditional scientific expertise (which is often generated by government institutions) and in local knowledge based on the local context.

In the USA, the importance of local context can be seen in the rejection of traditional scientific knowledge by some under-represented minority communities. For example, folk belief embedded in the African-American community attributes the AIDS epidemic to a deliberate attempt by the US Government to eradicate African-Americans; based on both general and specific instances of racism in the USA, this folk belief persists despite traditional scientific evidence pointing to a more natural origin of the disease. In another example, many low-income communities in the USA deeply distrust government scientists' statements regarding the risks of specific pollutants and chemical hazards; they are acutely aware that waste sites and other locations for hazardous materials are statistically much more likely to appear in low-income communities. Given these experiences in the developed world, scientists, scientific institutions and government agencies in the developing world need to consider how they can build scientific communication programmes that provide both solid technical information and opportunities for input and dialogue with local communities.

Public perception of science and anti-science as counter-culture

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In modern world science, fundamental science should be seen as part of culture. Historically, this is not a recent event, beginning in Europe really in the 17th century. The first steps were those made by Copernicus in astronomy and Vesalius in medicine. At the time of the Renaissance, when the whole edifice of mediaeval life and ideology was crumbling, new science was boldly establishing itself. From the beginning very practical issues of medicine and anatomy of the human body became an object of study. Dissections were performed in an anatomical theatre – cadavers were difficult to get and public interest was great, for not only medical students attended these dramatic performances. The ideas of the new astronomy challenged the established and deeply entrenched picture of the world. The rate that great discoveries were made is astonishing, even by the standards of the 20th century. To most people, telescopic discoveries by Galileo probably mattered as much, if not more, than modern adventures in space. On the other hand, superstitions abounded and in Europe, reportedly, 30 000 witches were burnt or drowned, more than ever before, indicating the polarization of society and frustration in the minds of the people.

Kepler, with the mind of a modern theoretical physicist, as was remarked by Einstein, had to save his mother from being burnt for witchcraft. He was a practising astrologer, deciphering, for very practical reasons, the message of the stars and planets, the motions of which he managed to describe by laws that since then bear his name. At the same time the Thirty-Year War was rewriting the political and religious map of the continent, much as the World Wars of the 20th century did in terms of social order and ideologies. It is no accident that historians are keen to draw analogies between these two dramatic and eventful chapters of history. That is why to assess the place of science in the modern world properly we have to broaden our vision and see the events in a greater perspective of time.

After the scientific revolution of the 17th century and the Enlightenment came the Industrial Revolution. In most cases the inventions of that time were not based on science. The invention of the marine chronometer, of the steam engine and of the loom came about by the ingenuity of engineers, by trial and error, with a rather rudimentary understanding of the scientific basis of these developments. In the 19th century the figure of an engineer, often a gifted entrepreneur and manager, became symbolic of progress. When the electrical industry began to develop, fundamental science became the basis of new developments. If the first inventions in telegraphy did not require a detailed understanding of the physics involved, the success of transatlantic telegraphy demanded the scientific expertise of Lord Kelvin, one of the great physicists of the 19th century. Since then almost all great inventions have been based on a scientific understanding of the phenomena used. As a result, a solid knowledge of science and mathematics has become a necessary part of the training of an engineer.

In the 20th century all major inventions were based on and derived from science – physics, chemistry and biology – practised as a common, truly global intellectual enterprise. Moreover, the intimate connection between applied and fundamental science was seen in the way applied science was organized, when large industrial laboratories were set up, be it Philips in Holland or Bell Laboratories in the USA, the laboratories for aeronautical research that served the aircraft industries or the large laboratories of the chemical and pharmaceutical industries. This pattern of industrial internationally based development is well established. Most of these research centres are also connected to universities and ever since the Industrial Revolution technical universities and institutes of technology have grown in number and significance.

It should be noted that this system of training and development was also an essential part of the effort responsible for the arms race. By the end of the 20th century it had grown to monstrous proportions, having far outgrown its purpose to serve country and society. In the Soviet Union the military-industrial-scientific complex had certainly contributed to the defeat of the system it was supposed to defend and Russia still cannot get rid of its legacy: managerial, technical and moral.

If applied science is now the basis of most, if not all, technology and its usefulness is beyond doubt, the case for fundamental science is more complex. First is the motivation – for applied science it is that something useful is expected, that justifies all effort and expenses. In fundamental research the motivation is the search for the unknown, for new knowledge, to reach an understanding of nature, of the human being, for that matter. This is the main stimulus, a powerful and very personal force, driving the scientist against all the odds of nature and the established wisdom. In other words, the scientist is always a dissident and often his dissidence goes beyond science. The applied scientist, the engineer, is in general a master of compromise, a member of a system, rather than a lone individual, the majority of one, who is right.

This difference in attitudes and in motivation should be taken into account. In the first place the cost of fundamental science is approximately 10 times less that of applied research, that is again 10 times less than the turnover in a science-based industry. On the other hand the time-scale is different. A new product can be produced in a year or two; a project in applied research will take some 10 years and the results of fundamental science take decades to have a pronounced effect on industry and society. These are but estimates, order-of-magnitude numbers, but they show the relevance of these major departures in the human endeavour in science and industry.

To this one should add the difference not only in motivation but also in the personal character of the parties engaged, which are often not taken into account. Discoveries in fundamental science are usually made by young scientists who, in their twenties or early thirties, are at the height of their intellectual performance and best equipped for great and original discoveries. Later in life interests may shift from fundamental science to other fields. An applied researcher usually matures later and managerial skills may come even further in age, although any number of exceptions can be quoted. During their careers, many scientists engaged in fundamental or applied research may spend both time and effort in teaching. Much in innovation and discoveries depends on how society supports and appreciates the effort of scientists.

In assessing the place of science one has to take into account that the system, as it is here described, really took a very long time to develop. Its roots go far into the past, to the Greeks and the Middle Ages, to the long gestation period of European culture, where religion and philosophy were precursors of natural science. This complex and dynamic pattern of the way science and technology, discovery and innovation, training and management is organized in the modern world should be kept in mind when discussing the connections and impact of science on society. The pattern first developed in Europe. In different countries the way things happened varied, but the general development was much the same. Those countries, like the USA or Japan, which imported the system from Europe and further developed it did not have this background of history. When short-range commitments and practical results dominated the attitude towards science, this was an advantage but it led to difficulty in creative training.

This happened when the results of science had not only to be of practical usefulness, but also had to become part of culture in the broader meaning of the word. That is why the issues of science and society are now a factor of growing importance. Their significance is all the more noticeable in that the rate of growth of the scientific endeavour has gone far beyond the level of understanding not only of the content of science but of its deeper message as a contribution to modern culture. Mesmerized by the immediate usefulness of science, under the influence of the short-range pressure of the market, of advertising salesmanship of the media and of the pragmatic trends in modern education, most people are lost in the brave new world of science and technology. And when the gap is so great, people not only cease to understand any more what is happening, they lose trust, then get afraid and reject much that comes with science. Finally, the void left is filled with pseudo-scientific, mystic or fundamentalist ideas, taking us far back in time and history.

The symptoms mentioned are getting all the more pronounced and are spreading worldwide. A new crisis is now developing and going well beyond the issues of scientific literacy and deficiency in school education. Moreover, it may be that both illiteracy and lack of education are the result of the crisis rather than its cause. In complex matters of social behaviour, cause and effect are often mixed up and both can be due to some deep-lying fundamental reason. In the case considered, on the one hand these anti-scientific and irrational trends and on the other hand the veritable blow-up of the scientific endeavour may be traced to a common cause.

The reason may well be in the very force driving the development of humankind over the ages. Recent research has shown that, since the beginning of the growth of humankind, right from the early stages of the human story, development was due to a cooperative interaction, that is proportional to the square of the total number of people in the world. This growth rate is faster than exponential growth and diverges at a finite moment of time: in fact in 2025! This hyperbolic blow-up growth describes the population explosion, so noticeable in the 20th century, that is now cut off by the population transition: in the foreseeable future the global population will stabilize at 11 billion to 12 billion, twice the size of the world population of 6 billion in the year 2000.

In other words, humankind is just passing through the period of most rapid change that ever happened. A change not only in the number of people in the world, but also of all conditions of development on Earth. This may sound like a broad generalization, but it is substantiated by looking at other conditions of life at a personal and societal level. This rapid growth has led to stress and strain, and finally to a disruption of the connections joining society at large. A particular in-depth look at what is happening has been made by Francis Fukuyama in his recent book *The Great Disruption: Human Nature and the Reconstitution of Social Order* (Free Press, 1999).

It may well be that the collapse of reason, of the growing gap between material civilization and culture is but part of the great disruption, tearing up society and human consciousness. For there is no time for developing the long-term and more delicate forms of social organization that are responsible for our understanding of ourselves and the world. Hence the fall back to primitive ideas, long ago embedded in our consciousness, that cannot keep up with scientific and technological ‘progress’. Humanity is simply not yet ready to deal with the power of nuclear energy and, finding no better way than inventing the most terrible bombs ever built, is now baulking at nuclear power stations. Certainly Chernobyl did not help and only showed that, both socially and psychologically, we are not ready to deal with nuclear energy.

If nuclear weapons and Chernobyl provided more than enough for a negative image of matters nuclear, the case of the cloning of Dolly showed that we are also not ready for modern developments of embryology and genetics. These are but practical results of fundamental studies in physics and biology. But the resentment towards science goes further: a new surge of fundamentalists is claiming a place for creationism in schools and in teaching. Numerous cults are challenging established traditional religions, the whole philosophy of post-modernism in a way pronounces the futility of the scientific enterprise. The danger is that these trends could unite into an organized challenge to reason. Then science will have a difficult time finding its place in society both professionally and morally, as scientists cannot divorce themselves from a broader responsibility for the results of their discoveries.

Profound ethical issues have to be faced not only in publicly practising science, but also in teaching students who themselves are often brought up in the immoral, if not amoral, modern world, where the lack of ethical norms is the result of the rapid changes the world is passing through. In these conditions, what matters most is the sense of responsibility that finally all members of society face. The larger the power or influence, knowledge and issues at stake, the greater the responsibility. If in the past religion could claim to be the custodian of moral values, in the modern world this seems no longer to be the case. Some thought that science, as an objective and universal system, could take over this function in society, but this, as our discussion shows, is far from happening. So the issues of moral values go unresolved, partly because there is not enough time and partly because science is slow to recognize and face this new challenge. It is no accident that some leading academies now consider the development of public attitudes to science as a major responsibility towards society. Unfortunately, education and the mass media in most cases are hardly collaborating, to say the least, in these matters going well beyond science itself.

Now stepping into the 21st century, into the Third Millennium, the future world is to be one with a stabilized population: a world where the growth of human development will no longer be driven by numbers, be it growth in numbers of people and space, power and guns, measured in megawatts or megatons. Is it to be development in ‘quality’ of life, rather than ‘quantity’, which has dominated humankind since its very beginning. This is a real challenge to our civilization, to culture and science. Will this new world manage to resolve the predicament of our body and mind, looming on our common horizon?

Public understanding of science: essentials and its practice

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The popularization of science has direct bearing on social progress and national prosperity, as has been proved since ancient times, even long before the appearance of modern science. The influence of science on society is determined by the level of development of science, on the one hand, and by the extent of public understanding of science, on the other. It is through the popularization of science that all scientific achievements without exception produce an enormous impact on society. Many scientists like to use important scientific events for the historical division of science, regarding the use of fire – the most important scientific discovery in early human history – as the beginning of civilization, and the advancement of tools, materials, energy resources and science information as markers for the Old Stone Age, New Stone Age, Bronze Age and the subsequent Steam Age, Electric Age, Atomic Age, Information Age and so on. All the scientific achievements used as symbols of different ages are scientific inventions or discoveries that have been popularized to a maximum.

Exploration is the life of science, while popularization provides science with a base for its existence and development. People love science precisely because it can be quickly turned into social wealth, into a precious kind of material and spiritual wealth. The power of science lies in popularization, which in a certain sense is the end result and ultimate aim of all scientific pursuits.

In human history numerous bright scientific ideas have occurred, yet many of them have not left any trace in civilization. An important reason for their obscurity is that they were not or could not be popularized – in other words, they were not or could not be understood by the public, which, as the main body of social activities, only takes part in and gives support to things it can understand and deems important.

In the period of scientific enlightenment, the public came to understand scientific activities in a spontaneous and natural way. At that time, these activities were closely related to life and people could easily judge, accept and utilize their values through experience and common sense. After the 17th century, modern science appeared in Europe, giving birth to a vocabulary, symbolism and mode of thinking of its own, distinguished from conventional language and logic, as well as to a community of its own to meet the needs of scientific development. In those years, however, the great scientists still sought to express the profound scientific ideas in a language not divorced from the common people, a language through which the public could understand science. *The Dialogue Concerning the Two Chief World Systems* – Ptolemaic and Copernican – a masterpiece of Galileo, the founder of modern science, was written in a language understandable to the public in describing the two entirely opposing systems and their influence on mankind, a language that is by no means abstruse even to readers today.

Historically, all scientific activities have been accompanied by efforts to promote public understanding of science, efforts that had been going on quietly even before their significance became clear to people. As an essential part of culture, modern science has spread from its cradle to many places, from scholars' libraries and artisans' workshops to the broad masses through the emulation of advanced modes of production, through the circulation of commodities, through tourism and exchanges, and through wars and trade. But such spontaneous efforts to popularize science are a slow process with great limitations and far from complete.

Today, our world is confronted with the serious problem of public understanding of science, which is exerting an influence upon mankind on an enormous scale as never before – upon economic prosperity, social progress and all individuals' welfare. However, science is getting farther and farther beyond people's common sense. It is difficult – even for those with the richest imaginative power – to get, merely by means of their experiences and instincts, an exact understanding of modern science and the changes brought about by it, for people to judge their values and meanings against the background of their experience and knowledge. The contradiction between the functions of science and lack of knowledge has aroused attention and concern among more and more people, who consider it to be a new challenge to the world today.

In the final analysis, public understanding of science comes through education in science as an important constituent of general education. Generally speaking, one spends only one-quarter to one-third of one's lifetime receiving school education and the bulk of it acquiring knowledge from society. Science is developing by leaps and bounds and technology is being renewed in shorter and shorter cycles. People who are fortunate enough to live in the present-day world will be able to see in their lifetime only, a few generations of some major technological changes, and they can only rely on the social education of science for accumulation and renewal of knowledge. Our efforts to popularize science in society will to a great extent affect people's concepts and social behaviour. In measuring a country's educational level, we should take into account not only the condition of its school education, but also the depth of the public's understanding of science.

Nowadays, with the growing content of science in productive labour and socio-economic activities, workers are finding themselves more and more unequal to their work merely by relying on their physical energy and elementary knowledge. The level of a country's productive forces is determined by its workers' cultural and scientific level, which in turn is determined by the extent of the popularization of science – something that will have direct bearing on the degree of socialization of labour in science and on the development of production and economic prosperity.

At the same time, the popularization of science will produce a deep effect on ethics and our outlook on values. Science is an uplifting force that will raise society to a higher moral level, although, as one of its odd characteristics, it never proclaims a morality of its own. When dealing in a scientific way with the natural environment they are in and reasoning through the stern facts facing them, people will be brought into the sublime state of intellectual power and consciousness of universal laws.

Efforts to promote public understanding of science will, in a subtle and imperceptible manner, bring delights in the beauty of science and mysteries of nature, and afford enjoyment of creation.

But it always takes time to comprehend something of great importance. This is also true of the campaign for public understanding of science. An achievement in the popularization of science may not excite as much joy as the discovery of a gold mine: but it may have a far deeper significance to mankind and bring a far greater benefit to society than some tangible wealth. On the other hand, neglect of the popularization of science may not bring about a visible loss as shocking as a natural calamity, but an invisible loss which is far more harmful. The popularization of science is an undertaking that serves public interests and calls for the deep sympathy and concerted efforts of the whole society.

Sometimes, difficulties in the campaign to promote public understanding of science come from within the scientific community itself, which holds that the campaign has nothing to do with the cause of science, takes no interest in it and declines to assume any responsibility for it. As a matter of fact, public understanding of science will create favourable external conditions for the development of science and help foster more outstanding scientists. At present, scientists in various fields are working according to a more and more detailed division of labour and going deeper and deeper into their specialized research; they know less and less about other branches of science. As the saying goes at Oxford, 'The expert is one who knows more and more about less and less.' Modern science is characterized by the crossing of different branches, thus giving rise to new branches and leading to mutual infiltration among various branches and major breakthroughs in science and technology. Consequently, experts whose scope of vision is confined to a single small field will find themselves barred from the greater circle of multi-branched science. A scientific exploration may produce a great social influence, but this influence can be of real benefit only when it has gained full public understanding and enlisted effective public support – usually with the scientific explorer himself benefiting immediately from the campaign for public understanding of science. The times have made a new demand on scientists to view their cause against a broader background and to work enthusiastically, while making scientific explorations, to obtain a broader public understanding of science.

Owing to the wide differences in the division of labour and educational background, it is impossible for all people to be scientists. Nevertheless, it is possible for the general public to understand the basics of science, to understand the scientific methods of thinking, to understand the practical approach to scientific exploration, to understand the relations between science and society, to understand the potential of scientists and their limitations. We cannot expect all people to become composers, but they can appreciate and enjoy music and understand Mozart and Beethoven. Similarly, it's not easy to become a scientist, but it's possible for the public to gain an understanding of science and enjoy the fruits of science.

At present in China, there are approximately 2 000 kinds of popular science journals and around 5 000 sorts of popular science books being published every year. A certain number of renowned research institutions and university laboratories are regularly opened to the public for the purpose of helping them to keep abreast of current scientific progress and the activities of scientists. China has 340 million households and these own more than 300 million domestic television sets. The CCTV broadcasts its daily scientific programme at 8:00pm, the peak viewing time, transmitting scientific knowledge on special channels, in its efforts to build up an 'Information Expressway on the Air' between science and the public.

Public understanding of science is of special importance for the developing countries. To push forward such a cause, we would like to set forth the following proposals:

- UNESCO should map out standards of science education for the public suitable for different countries and regions, put forward the programme and plan for implementation as a lasting global activity for encouraging public understanding of science and accord necessary assistance to the developing countries.
- ICSU should sponsor an international academic conference entitled Public Understanding of Science, inviting scholars from the realms of natural science, social science and human science for discussions, for the purpose of studying and searching for effective ways to disseminate scientific conceptions more broadly and develop a scientific spirit aiming at reaching greater common understanding.
- Both UNESCO and ICSU should encourage developed countries to set up science museums and organize scientific activities for youth and children.
- The governments of developing countries should be encouraged to include activities aimed at increasing public understanding of science in their national plans for development. This can be achieved in every country through education, including school education as well as science education for the whole society, so that each member of society can benefit from science education. It is, in fact, a right that every citizen should enjoy.

Science centres: a motivational asset

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Science centres are institutions that aim to explain scientific principles to uninitiated persons by using interactive exhibitions that may or may not contain historical artefacts. They are public spaces and, if intangible collections of ideas and principles are considered collections, they are also a special kind of museum. In fact, the line between science centres and science museums is a matter of taste. For a summary of the history of these institutions, see for example Gil (1998) or Persson *et al.* (1999).

Science centres typically use interactive exhibits, involving their visitors in active experimentation. When working properly, these provide the visitor with a unique and thoughtfully devised opportunity to enter into a dialogue with nature itself. Although the majority of science centres deal mainly with natural sciences, there are also centres presenting humanities and social sciences. While the exhibits are often described as 'hands on', they certainly aim to be 'brains on': starting intellectual processes, solving problems and providing answers.

Science centres are part of the movement striving to enhance public understanding of science. For a brief account of the positioning of science centres in this movement, see Persson (1996*a*). The educational value is subject to a growing literature and at least learning behaviours are reported in science centres (for reviews, see Borun *at el.*, 1995; Barriault, 1998). In addition to the educational value, there are at least two reasons to visit science centres: the visit is a social event (Falk and Dierking, 1992) and it provides a unique opportunity for a lay person to perform experiments on real phenomena (Persson *et al.*, 1999).

The rapid establishment of new science centres around the world in recent decades and the size of the industry today imply a popular appeal. Science centres may provide an important contribution to public understanding of science. However, in a changing world, these institutions must also be open to change and to the questioning of current policies and practices (e.g. Persson, 1996*b*; Bradburne, 1998; Farmelo, 1998; Kotler, 1999; Lusaka and Strand, 1998).

This paper discusses the size of the science centre industry, the contents of the product, the possible impact and the challenges ahead and concludes with an overall assessment of science centres as institutions of informal learning.

The size of the industry

Beetlestone *et al.* (1998), analysing data provided by the Association of Science-Technology Centers (ASTC), show that there has been a 30% increase in the number of science centres each decade since the 1870s. According to data presented at the 2nd Science Centre World Congress in January 1999, there are about 1 200 science centres in the world today, attracting an attendance exceeding 184 million visitors each year. Economic turnover exceeds US$ 1.4 billion per annum. The corresponding figures collected at the 1st Science Centre World Congress in 1996 were 1 000 science centres and more than 150 million visitors. Caution should be exercised when inferring that there has been a 20% increase in three years, as the statistics are not comprehensive. Still, it seems difficult to avoid the conclusion that the industry is growing exponentially. The vast majority of science centres have existed for less than 20 years.

For the purpose of the Science Centre World Congress statistics, the definition of a science centre is broad: any institution providing access to the public for the purpose of popularizing science and using an exhibition as at least one of its tools could be included. However, the attendance figures are more reliable, as they represent the lower limit.

In a recent paper, Bradburne (1998) questions the growth in the science centre industry. He maintains that the growth is due mainly to new institutions being established and that many existing centres face stagnation. However, a survey of the data reported by ASTC for the last two fiscal years (1997 and 1996, Anon., 1999) does not lend support to this view. Less than 10% of the institutions reported a decrease in attendance exceeding 10%. In fact, 78% of the institutions reported increasing attendance figures. However, long-term fluctuations in museum attendance should be expected, reflecting demographic trends (Mintz, 1998).

Many science centres rank among top tourist attractions in their respective countries. One-third of the American population pays a visit to a science centre every year. The corresponding figure for the UK is 16%, for Scandinavia 10% and for India 0.5% (Persson 1996*b*). The figures show that science centres have popular appeal, i.e. that large numbers of people find it worthwhile to pay them a visit.

The contents of the product

When considering the contents of science centres, most scientists would naturally think about the scientific subjects covered in the exhibitions and programmes. However, the museum visit contains much more: it may provide a contemplative space, a sociable encounter, distinctive shopping facilities and family quality time (Kotler, 1999). In fact, a museum visit is an experience containing many variables, perhaps reflecting a shift of the entire economy towards experience selling (Pine and Gilmore, 1998).

The overall museum experience of a visitor is an outcome of an interaction between the personal context, the social context and the physical context. The physical context includes exhibits and labels, but many other variables as well (Falk and Dierking, 1992). Visitor agendas influence their behaviour and the outcome of the visit (Falk *et al.*, 1998).

Science centres tend to focus on natural sciences, although there are some notable exceptions (Persson *et al.*, 1999). Of the scientific subject areas covered in their exhibitions, physics is probably the most prevalent. Farmelo (1998) recently voiced the concern that science centres are not mirroring scientific priorities. In physics there have been three revolutionary developments during this century, namely relativity, quantum mechanics and chaos, and he noted that science centres have dealt effectively only with the last one. He concluded that science centres have been best at presenting science established during the past three centuries.

The critique of Farmelo (1998) is essentially correct and reflects the fact that science centres focus on hands-on experimentation as their main medium. This may result in a self-imposed limitation of contents. Other museological instruments and presentation techniques may be better suited for presenting, e.g. current research topics (Persson, 1997) or topics that do not lend themselves to visitor manipulation. There is, however, a continual development taking place.

The impact of science centres

A common conclusion among practitioners in the field is that data on the impact of science centres, on learning or more generally, are scarce, anecdotal and narrow in scope (e.g. Persson 1996*b*; Beetlestone *et al.*, 1998; Bradburne, 1998; Farmelo, 1998). This is without doubt true for societal impact studies, where indeed methodological problems remain to be solved. However, for impact on learning there is a vast literature, including monographs such as that of Hein (1998). In museum studies, learning is often understood in the experience-based or constructivist sense of Dewey (Ansbacher, 1998).

Learning in a science centre is informal and care should be taken when studying it that the methodology does not impose restrictions on the outcome. Informal learning is highly personalized and depends on visitor agendas. In recent studies, efforts have been made to define learning behaviour in a way that is not predetermined by the researcher (Barriault, 1998). The approach has yielded interesting results in uncovering learning behaviour patterns and relating them to depth of learning. Barriault (1998) defined 11 learning behaviour patterns based on actual observation of visitors and she related these behaviour patterns to three depths of learning (initiation, transition and breakthrough).

A perusal of the literature shows that learning behaviours can be discerned in several studies (Stevenson, 1991; Borun *et al.*, 1995, 1996; Serrell, 1997). A museum visit may be recalled after years or decades (Falk and Dierking, 1992). There is a lot of interaction in social groups, such as families. Science centres seem to do quite well in the affective portion, influencing and enhancing motivation (Salmi, 1993; Meredith *et al.*, 1997). In addition to the published literature, there is a great number of internal exhibit evaluation reports in various science centres, often including interviews with visitors, which support the overall conclusion that visitors seem to learn in science centres (e.g. Craven and Paisley, 1999). In addition to written reports, there is much anecdotal evidence. Science centre professionals bear witness to intensive learning experiences among visitors during exhibition visits. This is usually deduced from interaction with the visitors.

The challenges ahead

Science centres, as social institutions, have to adapt to the changing environment and develop suitable ways of delivering the product: a leisure experience with a science angle or content (e.g. Mintz, 1998; Persson, 1998; Kotler, 1999). However, there are many challenges and one may indeed question whether a deliverable product exists.

Bradburne (1998) in his recent critique of the science centre industry concluded that the industry is doomed. Science centres do not contain historical collections and therefore have no long-term attraction. Their temporary exhibitions will be outcompeted by the electronic media. They show science out of context, they misrepresent scientific activities and their mission has become irrelevant. Instead, a new kind of informal learning institution is needed, focusing on lifelong learning.

One could immediately react to this critique by saying that any institution defined as unwilling to change is doomed. So would be the science centre. However, in reality, science centres are changing (Persson, 1998; Persson *et al.*, 1999). They are moving towards this new kind of informal learning institution, providing for example services over the Internet, public debates and programmes of different kinds in addition to traditional hands-on exhibitions.

There are probably two main reasons to believe in the future of the science centre: a visit to a science centre is a social event (Falk and Dierking, 1992), and it provides a chance to carry out experiments with real-world phenomena, maybe even to meet a scientist (Persson *et al.*, 1999), in contrast to computer simulations available over the web.

However, it would be foolish to disregard the critique of scientific shallowness, narrow scope or lack of context that may occur in science centre exhibitions (Bradburne, 1998; Farmelo, 1998). This is part of the challenge to the entire industry: to find ways of presenting and explaining science and research in a meaningful and relevant way. These new ways will include a closer cooperation with research institutions and scientists, as well as networking between science centres worldwide.

Conclusions

The approximately 1 200 science centres in the world today attract more than 184 million visitors annually. Economic turnover exceeds US$ 1.4 billion. These figures show that a large number of people find it worthwhile to visit a science centre. People go to science centres and museums in search of an overall experience, influenced by their personal agendas. Research shows that visitors learn or display various learning behaviour patterns in science centres and that science centre exhibits have effects on the motivation of visitors. Science centres continually need to develop exhibitions and programming in order to meet the changing needs of their audiences. Altogether, science centres provide an important channel for presenting science to the general public.

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Science in the Third World: a paradox of prestige and neglect

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I have been invited by John Durant to discuss here the public perception of science in my native country, Argentina. I will give first a general introduction to what I have called the paradox of prestige and neglect that is science in a Third World country. I will then develop two examples of evidence of this paradox.

One of these is the attitude of successive Argentine governments towards science programmes in the country. And I will touch briefly on two scientific hoaxes separated by almost four decades, which indicate that there was little advance in the social perception of science in Argentina in the second half of the 20th century. The other is the attention the Argentine media give to science news and particularly the imbalance between local and foreign science in daily newspapers.

When presenting my conclusions, I will emphasize the perverse effect of this paradox beyond Argentine science, because of the importance of scientific research as a means of maintaining the quality of general education, especially at the university level, and its impact on local control over imported technology in a globalized world market.

So let us first have an overview of the situation of science in Argentina and the Third World in general. A recent chart included in an article by Federico Mayor Zaragoza and based on UNESCO and Organisation for Economic Co-operation and Development (OECD) data represents global spending in research and development in terms of the percentage of each region's gross domestic product (GDP) allotted to science. The world average is 1.1%. The USA devotes 2.5%, Japan and the newly industrialized countries 2.3%, Western Europe 1.8%, Latin America 0.3%. Argentina, not shown in the chart, officially devotes about 1.2%, though some estimate it below 1.0%. But the contrast is even starker in terms of global spending. While US spending on research and development represents 37.9% of the world total, the figure for Latin America is a bare 1.9%.

Science, though, carries much prestige in the Third World, judging by what can be observed in my native

Argentina and other Latin American countries. Whenever a native scientist, for instance, obtains a Nobel Prize, he or she becomes a national celebrity. Even if he or she has been totally unknown to most of the population – including most of the intellectual elite – until the day before. Even if he or she has been working abroad for many years.

Bernardo Houssay, Argentine winner of the Nobel Prize for Physiology, was routinely included in every presidential retinue every time an Argentine president travelled abroad during the 1950s and 1960s. In the 1970s and 1980s, Luis Federico Leloir, Argentine Nobel Prize for Chemistry, routinely made the cover of popular magazines, even though almost none of their readers could identify the field of Leloir's work. In the 1980s, César Milstein, Argentine Nobel Prize for Chemistry, also became a national celebrity, even though he had had to expatriate himself to do research and had been living for decades in the UK, of which he eventually became a subject.

The Nobel Prize allowed Dr Houssay, who was a combination of scientist and statesman, to lead, reorganize and expand the Argentine national research system. It helped Dr Leloir obtain funding for a new biochemical research laboratory. But it had no local consequences in the case of Dr Milstein, whom some politicians tried to repatriate but failed, because they could not guarantee him minimal working conditions.

This prestige of science has today no correlate in social support for scientific research and scientists in Argentina and probably in most of the Third World. Though, half a century ago, the Indian Prime Minister Jawaharlal Nehru said that India, being a poor country, could not afford not to do scientific research, the message seems to have been lost in time. Research spending today on the Indian subcontinent accounts for about 0.6% of its GDP.

Most developing countries invested less and less in science and education in the latter part of the 20th century, both in absolute and relative terms, at constant values. There is even an internationally sanctioned ideology that Third World countries should not 'waste' their money funding research, as exemplified by the World Bank document *Argentina: from Stagnation to Growth* of the early 1990s. The document recommended that the Argentine Government dismantle the national research system and let only privately funded research go on.

Argentina had known, at that time, three recipients of science Nobel Prizes; in spite of funding problems, Argentine scientists were publishing their research work in respected international journals, and the Atomic Energy Commission was about to close the nuclear fuel cycle with indigenous technology.

Today, the globalization of economic markets seems to reinforce this idea of 'economizing' on research investments. Why waste time and resources doing research when you can freely import the most advanced technologies at international prices, the argument seems to run. There are at least two answers.

One of these answers, following an old Jewish proverb, is that if you are not ready to make the effort to attend to your own needs, why should other people feel inclined to do it for you? There actually is scientific research the Third World needs that nobody else is ready to do – such as vaccines, desertification or tropical agriculture. And it can be done with Third World resources. The other answer is, as the Argentine technology transfer expert Jorge Sábato once noted, that the higher and more advanced the technology you import, the more you have to know about its basics to be able to make rational and responsible decisions about it and to make the most of it. So in both cases you do need research in the Third World, but the effort seems still not to be perceived as being worthwhile. Science in the Third World is the Cinderella of national spending.

In Colombia, where I was last April, the Government has cut research spending by 30%, even though research represents less than 0.7% of GDP. In Brazil, because of the financial crisis, scientists' salaries have plummeted to a fraction of what they were a decade ago. In Argentina, efforts at 'rationalizing' the government research system have produced a decrease in the number of scientists and an increase in their average age.

One of the obvious and well-known consequences of this is that Third World countries suffer a permanent haemorrhage of trained scientists. These Third World scientists emigrate not only because of their low salaries, which are low not only according to international standards but also according to local individual income levels. They are urged to leave their countries because, having attained an international level of professional competence, they lack funding for the libraries, laboratories and fieldwork necessary to pursue their careers.

Let us now take a look at Argentina's science development in the second part of the 20th century, the first evidence of this paradox of prestige and neglect.

During the Second World War, Argentina was forced to rely on its own resources to substitute industrial imports from the warring countries in the Northern Hemisphere. This gave birth to a very diversified indigenous industry, which in turn called for a national research and development system. In the late 1950s, the National Scientific Research Council, the Industrial Research Institute and the Atomic Energy Commission were created and research was stimulated at the universities. Scientists and university professors' salaries, though not luxurious, were considered acceptable.

But as the memories of the war's problems with imports waned and the industrial countries started pressing to sell their goods and services again, local industry and, with it, local research and university education began to lose priority. This was compounded by the mismanagement of the economy, by political instability and by military regimes that looked with suspicion on any sign of intellectual independence. By the mid-1970s, the Argentine national scientific system was in a deep crisis from which it has never recovered. For political reasons, the nuclear programme has been almost completely dismantled, industrial research is almost non-existent, agricultural research has been partly privatized for the benefit of agrochemical companies and basic research stagnates.

In the early 1950s, the Argentine government became victim of a scientific hoax. A quack physicist persuaded the Government that he could produce nuclear fusion at room temperature. A fantastic laboratory was built for him on a secluded lake island in the Andes and about US$ 60 million in the currency of the day was spent in less than three years on the purported experiments. Soon all proved to be a fiasco. This story shows how eager Argentina's leaders were in those days for science and for the prestige it conveys and how ignorant about science they were, including the then president, Juan Domingo Perón, who personally became involved in the affair.

Three decades later, the Argentine Government was again caught by another scientific hoax. This time, a group of self-described 'cancer researchers' claimed it had found a cure-all for cancer. The Government, including President Carlos Saúl Menem, assured them they would be officially backed and special laboratories were built for them. Their 'discovery' was toted as a piece of national pride. When responsible scientists pointed out the total lack of scientific rigour in the purported research, they were ignored. But as the truth started to come out, the case was buried under a heap of legal and bureaucratic red tape. The 'magic bullet' against cancer fizzled out and the Government was forced to reorganize its scientific establishment. This second hoax proved again the naiveté and lack of seriousness of Argentine politicians and government officials with regard to science.

The treatment of science by the Argentine media offers another example of the paradox of prestige and neglect I pointed to at the beginning. Argentine science journalism, which enjoyed a respectable past in the 1960s and early 1970s, was at an all-time low after the end of the last military dictatorship. There were no science departments at newspapers, no local science magazines and very little science news apart from the routine Nobel Prize announcements. With the return of democracy at the beginning of the 1980s and the repatriation of many exiled Argentine scientists, a new interest in science emerged in the newspaper pages. Part of this interest was due to popularization programmes at Buenos Aires University and the National Scientific Research Council.

But a combination of what was perceived as the commercial failure of science journalism, an eagerness of newspaper publishers to attain high circulation and the failure of the scientific institutions to sustain their popularization programmes did not take long to produce an effect – to the point that once again science journalism has almost disappeared from Argentine newspaper pages and only the most sensationalist magazines survive. Whatever serious scientific information is carried by the Argentine newspapers these days is supplied by the wire services and on-line information services of international scientific journals and concerns mostly 'big science' (space, genetics) from developed countries in the Northern Hemisphere. It is worth nothing here that the Argentine 'quality' press celebrated euphorically the 'discovery' of the Argentine magic bullet against cancer and never came fully to admit it was a hoax, retiring to a sort of 'We will see what happens' attitude and reviving the public's hopes from time to time, even when the results of officially commanded research are negative.

I would like to come to my conclusions here, mainly with a prognosis on the effect of the neglect of scientific research on Argentine education, especially at the university level.

As I have pointed out before, the globalization of markets and the freedom to import advanced technologies do not eliminate the need for research. Scientific research is the foundation of a high-quality university education. Local research is needed to enable understanding of whatever is happening in science and technology around the world, and to train the doctors, engineers and technicians, and also the educators at the lower level of the education system.

If the quality, diversification and volume of research declines, it will by and large drag down with it the whole education system. And this in turn will diminish the capability to manage the advanced technologies available today for Argentina. So I think it is not exaggerating to say that science in Argentina is a paradox of prestige and neglect, as is probably true for many other Third World countries.

L'Afrique refuse-t-elle la science ?

Gervais Mbarga
Université du Cameroun, Yaoundé, Cameroun

S'il y a bien un continent auquel on doit appliquer le dilemme de la perception de la science par le public, c'est bien sûr l'Afrique.

Installée en effet aux confluents des questionnements et des crises historiques, culturels et aussi relatifs à la connaissance, l'Afrique, pendant de longs siècles, a pu être présentée comme un modèle de populations enfermées dans l'irrationnel, où la science subit la plus forte intention du rejet.

Cette analyse a fait recette pendant longtemps parmi les spécialistes et a contribué à nourrir et renforcer ce que l'on connaît aujourd'hui sous l'étiquette célèbre d'afro-pessimisme.

Pourtant, à regarder l'évolution actuelle de ce continent et spécialement ses méthodes d'appropriation de la science et des technologies, il y a lieu sinon de réviser ce point de vue, du moins de nuancer grandement sa force.

Dans cette contribution, nous avons la prétention de démontrer que, bien qu'oscillant encore entre le rejet et l'adhésion, une dynamique particulière s'observe en Afrique en faveur d'une domestication de la science et de la technologie.

Mais pour tenter de mieux appréhender ce phénomène nouveau et paradoxal au vu des positions couramment admises, il est instructif de revisiter la science et surtout l'enveloppement de la culture scientifique et technologique en Afrique pour comprendre comment le retard engendre dans ce cas la nouveauté.

Les facteurs d'incompréhension et de rejet

Inutile de revenir ici sur le tableau de la situation de la science en Afrique, continent connu pour son retard alarmant quant à la production et à l'accumulation de la science et de la technologie.

Ce tableau a été repris par plusieurs auteurs et il suffit de mentionner que l'Afrique noire ne fournit que 0,3 % de la production scientifique *mainstream* mondiale pour se fixer les idées.

Mais au-delà de cette production déjà minuscule, ce qui frappe le plus l'observateur, c'est le divorce entre la science, entendue comme somme de connaissances structurées et/ou expérimentées, et les populations africaines. Là encore, la liste des illustrations est connue : refus de la rationalité, sorcellerie, défaitisme, développement insignifiant de la structure sociale de la science ainsi que présence mitigée d'une infrastructure permettant l'éclosion de la science.

L'on peut trouver les racines de ce rejet de la science dans, au moins, deux directions : primo, le système scolaire mère du système social de la science et, secondo, ce que l'on pourrait appeler le service scientifique.

Le système scolaire

L'histoire de la science moderne occidentale sur le continent africain montre que celle-ci entre partout en Afrique par la voie de la colonisation socio-politique et économique dès la fin du 18ème siècle et qu'elle utilise pour se reproduire le système scolaire.

Lorsque le système socio-politique impose la division en Etats artificiels notamment, lorsque le système économique impose des cultures de rentes mal adaptées à la consommation locale (café, cacao), le système scolaire survient avec un ensemble de connaissances elles aussi assez mal adaptées et qui encouragent plus la spéculation que la résolution de problèmes précis.

Plus souvent, l'école arrache les enfants à leurs familles, à leurs langues, à leurs cultures, procède par humiliation et par violence, rappelant aux parents et aux enfants les travaux forcés et les réminiscences de l'esclavage qu'ils tiennent à oublier à tout prix.

Il n'est pas surprenant par conséquent que les produits de l'école et plus tard de la science soient ainsi voués au mépris des populations.

Le service scientifique

Plus que le système qui la produit, les services que rend la science constituent un autre objet de rejet. L'évaluation de l'impact de la science sur la vie quotidienne des populations révèle en effet une disette fondamentale. L'on ne peut affirmer sans apporter des réserves importantes que la science et la technologie ont contribué à l'amélioration immédiate des conditions d'existence des africains.

Au contraire, la dégradation de l'environnement et l'émergence de nouvelles maladies auraient tendance à renforcer la méfiance ambiante. Car en effet l'apparition de la technologie a complexifié la vie : le poisson de la rivière, l'animal des forêts, les plantes des champs traqués et menacés par les produits et équipements de plus en plus puissants, deviennent de plus en plus rares.

Traduction : la science et la technologie apparaissent comme destructrices de la qualité de la vie et du milieu.

De même, l'émergence de nouvelles maladies est souvent reliée, dans l'imaginaire populaire, à une science sans âme.

L'on citera d'autres facteurs toujours plus percutants permettant d'expliquer le rejet de la science : son coût humain, son coût psychologique, mental et financier, sa propension à l'instauration d'un ordre social qui bouleverse les statuts et les rôles habituels bouleversant, obéissant à des normes perpétuellement remises en cause donc non sécuritaires pour un milieu où la survie n'est pas acquise ; son origine étrangère véhiculant des visions du monde destructurantes et angoissantes.

Faisant l'addition de ces nombreux obstacles, les pessimistes de l'Afrique avaient déjà décrit une prospective catastrophique pour le continent.

Or, que voit-on en Afrique aujourd'hui ? Une appropriation, sans doute imperceptible encore, mais irréversible de la science et de la technologie.

L'adhésion à la science

Trois exemples illustrent ce mouvement d'un autre type qui, pour nous, représente la nouvelle adhésion africaine à la science et à la technologie. L'exemple, dans les technologies les plus avancées de l'Internet, celui du téléphone portable et celui de la pharmacie de la rue.

L'Internet

Il circule beaucoup de considérations à propos de l'Internet et en relation avec les pays pauvres spécialement d'Afrique. Il se dit notamment que voilà un autre outil qui enfoncera la distance entre le Nord et le Sud et contribuera à établir un monde à deux vitesses où le Nord va toujours plus vite et le Sud plus lentement. Cela est possible. Cela sera même la conséquence la plus immédiate du développement des nouvelles technologies de la communication.

Pourtant, ce qui est surtout visible et troublant aujourd'hui dans les pays comme le Cameroun, le Sénégal, l'Afrique du Sud, c'est un mouvement relativement important vers cet outil de communication pour rentrer en contact avec le monde et à la fois vendre, acheter et communiquer.

Un ami sénégalais, tenancier d'un cybercafé, me racontait lors de la Conférence des Chaînes en Communication de l'UNESCO (ORBICOM) son expérience. Des villageois ou des commerçants analphabètes se rendent régulièrement dans son café pour se mettre en contact avec le monde, chercher les meilleures offres des prix de l'arachide ou des marchandises pour mieux s'insérer dans le marché ou simplement pour assurer que les transactions qu'ils effectuent correspondent à la réalité du marché.

Cela exigera certes aux concepteurs d'Internet ou d'ordinateurs de rechercher de nouvelles ergonomies pour satisfaire des analphabètes par des icônes plus suggestifs, mais cela matérialise déjà une avancée au moment même où tout le monde pariait sur la résistance, la peur, le rejet.

Le téléphone portable

L'exemple du téléphone portable est encore plus spectaculaire dans les pays comme le Côte d'Ivoire. A l'instar d'autres pays africains, ce pays connaissait le téléphone avec toutes les difficultés inimaginables. L'arrivée du portatif et la restructuration du milieu ont provoqué un engorgement qui a dépassé les prévisions les plus optimistes si bien qu'aujourd'hui le téléphone fixe classique subit une concurrence sévère du portable qui lui-même s'est développé dans des proportions spectaculaires. Là également, on avait parié sur une lente pénétration et les résultats apparaissent surprenants.

La pharmacie de la rue

Il est vrai que cet exemple est à double tranchant. Dans toutes les villes africaines au Sud du Sahara, le phénomène de la vente des produits pharmaceutiques dans la rue est de plus en plus envahissant. Et il est toujours étonnant de voir servir une prescription par un jeune colporteur à première vue théoriquement ignorant de la chose médicale. Pourtant, la persistance de cette activité démontre qu'elle est lucrative et qu'elle développe une clientèle. Par ces temps de misère en Afrique, tous les expédients qui permettent de garder sa santé sont utiles. Pour ainsi dire, les médecins et les pharmaciens d'officine dénoncent en effet cette pratique de vente de produits pharmaceutiques incertains, dans des environnements inappropriés et dangereux.

Certes, mais le sociologue ne peut manquer d'y voir une entrée, par effraction certes, mais une pénétration quand même par de non-experts dans un milieu sévèrement quadrillé et gardé par les *gate-keepers* des sciences de la santé.

Conclusions

Au total, les exemples cités montrent bien comment les populations jeunes et moins jeunes ont décidé de prendre d'assaut, sans plus de peur, les outils scientifiques et technologiques.

Cette opération est rendue possible par quelques phénomènes identifiables dont certains se trouvent dans la logique scientifique :

- *Premièrement :* l'école se transforme graduellement, imposant une transformation des mentalités scolaires et des produits du système scolaire comme la méthode scientifique. On se rend compte qu'elle n'est pas simplement spéculation et esclavage méthodologique, mais qu'elle s'avère utile.

- *Deuxièmement :* le service scientifique est de plus en plus concret, rentable, manipulable ; il n'exige pas toujours de tous de longs apprentissages frustrants.
- *Troisièmement enfin :* on peut s'intégrer à la science et à la technologie sans devoir commencer le processus à son début. Il n'est pas nécessaire d'avoir un téléphone fixe avant d'accéder au portatif, il n'est pas nécessaire d'être ingénieur en informatique pour utiliser l'Internet.

J'ai dit que cette dynamique est relativement nouvelle et relativement imperceptible, mais elle fait la preuve qu'en Afrique c'est bien le temps de l'adhésion, au moins instrumentale, qui commence pour la science.

Thematic meeting report

John Durant
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Science is in a state of simultaneous prestige and public neglect, to cite the title of Martín Yriart's paper on science in the Third World. It is suffering from increasing levels of public ambivalence. Low levels of public knowledge of scientific endeavour do not in themselves explain this ambivalence towards science. As Bruce Lewenstein comments, there is no simple relationship between knowledge and support; in some contexts, the more people know about science, the less they support it. Various factors explain the phenomenon, like the 'overselling' of science, the high rate of change of science and the failure of scientists to exercise social responsibility in their work.

Why is formal science alone not sufficient to improve the relationship between science and society? Because public attitudes towards science (trust, confidence) are as important as public understanding of science. Even the perception of the purpose of science differs according to whether one is a member of the general public or of the scientific community. Surveys cited by Lewenstein show that scientists perceive science as open investigation of nature, whereas the public perceives science as using the natural world to provide specific practical benefits.

Sergey Kapitza considers that the usefulness of technology is today beyond doubt but that the case for fundamental science is more complex; the fundamental scientist is driven by curiosity, a 'dissident' as Kapitza puts it, contrary to the applied scientist, who is 'a master of compromise, a member of a system'.

Yriart suggests that, in the Third World, neglect of science is born of an erroneous belief that research is a luxury for developing countries. He considers that globalization of the economy has reinforced the idea advanced by the World Bank in the early 1990s that Latin American countries should 'economize' on research investments, despite the fact that certain areas of research are of little interest outside the Third World, such as vaccines, desertification and tropical agriculture. As a result of this ambivalence towards science, salaries for researchers are low and funding for laboratories inadequate, a situation which forces many top-level Latin American scientists to emigrate. Yriart concludes that globalization and the freedom to import technology do not eliminate the need for national research, which is crucial to understanding developments around the world and to training doctors, engineers and technicians, and educators.

Zhang Kai Xun considers that the scientific community itself is partly to blame for public ambivalence, in that it does not always show sufficient interest in science popularization. He sees the growing specialization within research as being in danger of isolating scientists. It is thus a positive sign that a number of renowned research institutions and laboratories in China now open their doors regularly to the public. He underlines the positive consequences of a greater public understanding of science, which would bring with it a deeper awareness of ethical issues.

For Kapitza, ethical issues are central to public acceptance or rejection of science. Religion can no longer claim to be the custodian of moral values. And humanity is not ready to deal with certain developments, such as nuclear power, genetics or embryology. Resentment towards science has given rise to creationism in teaching and other anti-science counter-cultures. An ever-deepening crisis leading to the propagation of irrational trends goes well beyond the issues of scientific literacy and deficiency in school education.

Rather than its being the cause of growing public distrust, Kapitza suggests that scientific illiteracy may even be a consequence of public distrust born of an incapacity to keep up with the rapid pace of change today. There is simply not enough time to assess ethical issues before science moves on to the next discovery. Kapitza cites the cloning of Dolly as a case in point. He proposes tackling these ethical issues not only in publicly practised science but also in the teaching of students who themselves are often being brought up in an immoral – or even amoral – modern world. The solution, in his view, is for fundamental science to come to be perceived as part of our culture.

Gervais Mbarga speaks of ‘afro-pessimisme’ and of the divorce between science and African populations. For him, this divorce has been brought about partly by an inappropriate education system imposed by colonialism which has alienated youth from science. Yet public rejection of science is motivated more by the lack of concrete applications of science than by the system that produces science. Populations witnessing the deterioration of their environment and the emergence of new illnesses are becoming, if anything, even more distrustful than before. Science and technology appear to African populations as destructive of their standard of living and of the environment.

On another continent, Yriart compares two scientific hoaxes separated by four decades to illustrate the disappointing progress in the social perception of science in Argentina. That the country’s leaders should have reacted to both hoaxes with naïvety reveals, in Yriart’s view, a combination of eagerness for science and the prestige it conveys and a glaring ignorance of science. The desire to keep up appearances at all costs led the Government to ignore the warnings of responsible scientists and, once the hoax had been exposed, to bury the case under bureaucratic and legal red tape.

According to Yriart, the paradox of prestige and neglect of science is also reflected in the media. Science journalism in Argentina has declined in quality, owing to various factors that include the military dictatorship and, once democracy was restored, the perceived ‘commercial failure’ of science journalism. Today, science journalism has almost disappeared from Argentine newspapers, the casualty of a race among journals for high circulation built on sensationalism and of the failure of scientific institutions to sustain their popularization programmes launched in the early 1980s. Most serious science carried by Argentine newspapers is now imported from abroad. Moreover, even today, the Argentine ‘quality’ press continues to have great difficulty in admitting that it was taken in by the hoax of a ‘magic bullet’ against cancer.

In some cases, science has not even been directly to blame for the negative experiences which have fuelled public distrust of science. Lewenstein cites quantitative surveys of the US public which reveal strong distrust of US government scientists among some under-represented minority or low-income communities, distrust engendered by past experiences of racism or other discriminatory government action, such as the selection of low-income areas as sites for waste disposal.

So, how does one go about fostering public acceptance of science? The key lies in forging a new and improved relationship between science and society based on mutual trust and confidence. Lewenstein urges the developing world to learn from the mistakes of the developed world by building scientific communication programmes that provide both solid technical information and greater dialogue with local communities.

Despite the prevailing ambivalence towards science, there are encouraging signs that things can be improved. Lewenstein concludes that studies in the developed world and particularly in the USA show that the general public perceives science as being beneficial for society. Per-Edvin Persson demonstrates that public interest in science is high, as evidenced by the explosive growth of the science centre movement worldwide. And, for Kapitza, it is no accident that some leading academies have come to consider developing positive public attitudes towards science as a major responsibility towards society.

Mbarga cites three examples of public acceptance of science in Africa: the Internet, the mobile ’phone and the ‘street chemist’. The Internet is perceived as a commercial tool and a means of communication, while the mobile ’phone is competing successfully with the classic telephone. As for the ‘street pharmacy’ even if the practice is denounced by doctors and professional chemists, it suggests – as do the other cited examples – a dawning acknowledgement by non-experts of the practical usefulness of the fruits of science.

Participants in the thematic meeting agreed that key elements in improving the relationship between science and society included encouraging more interdisciplinary science from which scientists would gain a broader understanding of key issues; improving scientists’ understanding of the public; and exploiting the potential of new forums for encouraging dialogue and the exchange of ideas and experience in the field of science communication.

Participants recommended that relevant research in the social sciences be used to improve our understanding of the relationship between science and the public globally; and that UNESCO host a conference on public communication of science and technology, to explore key issues and identify a programme of action.

The last word should perhaps be left to Kapitza, who reminds us with poignancy that public expression of distrust of science has mellowed over the centuries. Tracing modern science back to the 17th century, he cites the example of Kepler, who had to save his mother from being burnt at the stake for witchcraft.

Introduction

Abdulaziz Othman Altwaijri
Director-General, Islamic Educational, Scientific and Cultural Organization

Assalam alaikum warahmatu Allah Wabarakatuh

It is a privilege and an honour for me to be present here at this thematic meeting on Science for Development co-sponsored, within the framework of the World Conference on Science, by the Islamic Educational, Scientific and Cultural Organization (ISESCO).

While science has brought immense benefits and opportunities for people in the North, the South has failed to harness the benefits of technological advancement for socio-economic development. Domestic and international support has helped in the training of scientists and engineers, and boosted research facilities and technological capacity-building through transfer of technology and other means. However, all these support programmes have not resulted in any impressive economic progress to meet the immediate requirements of countries in the South. The disparity existing between the North and South is, therefore, continually being aggravated. Apart from declining economic conditions, the major reasons for this fiasco lie in faulty planning, lack of commitment, meagre education and training facilities, inefficient production facilities, inadequate research facilities and feeble organizational frameworks.

The desire by man to improve his condition and his driving curiosity to learn about nature are considered the two major driving forces for achieving scientific progress. Lack of commitment by the South is one of the major obstacles in the development process. National commitment, serious political will at the highest level and government financial support are *sine qua non* conditions for scientific development. The South should assess and evaluate its scientific development system and allocate at least 1% of gross national product (GNP) to science and technology.

Non-availability of an appropriate skilled workforce and qualified scientific and technological manpower is also one of the main reasons for the ditheringly slow progress in the South. In advanced societies, new scientific and technological innovations pervade almost every aspect of daily life, resulting in continual training leading to the acquisition of basic technological knowledge and related social skills. Due to the late introduction of these technological innovations, new products and processes in the South, the basic knowledge and skills imparted to the workforce soon become obsolete and redundant due to changed requirements for work. To meet the emerging human resource requirements for technology innovations, it is necessary to revise the role of knowledge-creating institutes and to tailor education programmes and curricula in response to new technological requirements. Vocational and technical training should be conducted in accordance with the requirements of the production sector to avoid unemployment and redundancy problems.

Appropriate facilities for women's development is another important necessity for the socio-economic development of a country, which is neglected in the South. As a result, the percentage of women in scientific fields in the South is extremely low compared with the North. There is a need to design a specific strategy to provide equal educational and training opportunities and to involve women in industry, academic and scientific institutions.

ISESCO is playing an active role in building the scientific and technological capacities of the Islamic World. A strategy for scientific and technological development has already been drafted and adopted by the Eighth Islamic Summit Conference held in 1997 in Tehran. We will discuss the implementation mechanisms of the strategy in another coordination meeting during the World Conference on Science. For achieving sustainable socio-economic development through scientific and technological advancement, we need to organize ourselves, learn from each other's experiences, devise strategies and embark upon programmes.

I am confident that, from the deliberations of this august assembly of distinguished scientists and thinkers, we should be able to prepare the guidelines which would give direction to strengthen the scientific capacities in the South.

Thank you very much and I wish you success in your deliberations.

Wassalamu alaikum warahmatu wabarakatuh

Science and survival in the coming decades

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The developing world will face numerous problems and challenges in the coming decades. In most of the developing countries, much of the effort needs to be directed towards bringing social equality and improving the overall quality of life. Some of them will have the unenviable task of pursuing efforts in science and technology (S&T) to solve pressing problems of a vast population, on the one hand, and to compete with the advanced countries in frontier S&T on the other. Efforts in S&T in developing countries can be categorized as follows:

- those related to solving pressing problems of mankind related to health, food and nutrition, shelter, etc.;
- those related to crucial infrastructure elements such as energy, communications and transportation (education and capacity in science should also be included as infrastructure requirements, since without them there can be no real progress);
- efforts in areas related to the unique features, strengths and resources of the country concerned (e.g. making use of the natural resources, special skills and manpower available, crucial needs of the country in areas related to health).

Besides providing support to these three types of efforts, basic science and science education deserve utmost consideration. It is important that developing countries develop national development strategies where S&T is properly integrated into the socio-economic plan.

As we approach the 21st century, it is imperative that developing countries prepare a time-targeted agenda for action. A typical list would be as follows in the table below.

Table 1.

Preparation of S&T-based national development plan	2002
Investment in R&D (1-2% of GNP)	2005
Universal primary education and scientific literacy	2005
Safe drinking water for all	2005
Food security and eradication of malnutrition	2010
Eradication of malaria, polio and other diseases	2010
Exploitation of specific natural resources (related numerals, etc.) and setting up of the concerned industry	2010
Improvement of science departments in the higher-education sector to bring them up to standards in advanced countries	2015

Clearly, there are many problems that developing countries need to tackle on a war footing and they include improving infrastructure, making use of the advances in information technology and above all inculcating an overall awareness and scientific temper among the masses. I believe that the mechanism to reduce the imbalance in development or the gap in well-being has to be based on knowledge. The knowledge base and, in particular, capacity in science will be a crucial element in determining how developing nations will fare in the highly competitive atmosphere of the 21st century.

Science, development and globalization

Ahmad Jalali
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The inequalities that characterize our world and cause its division into two different parts – developed and underdeveloped, North and South – are usually expressed in terms of difference in gross domestic product (GDP), per capita consumption of energy or other indicators. Notwithstanding the deep discrepancy that exists in all these domains, the gap between these two parts of our world can perhaps best be shown by their respective share in scientific production.

According to UNESCO statistics, in 1990 only 4% of the total world research was conducted in the developing countries. This shows the very small contribution of these countries compared to the share of the developed ones, that is 96%. The distribution of this research among the developing countries is no more equitable, the lion's share going to a few countries which are relatively more developed and more powerful. Consequently, most developing countries make practically no contribution to world research. Although, compared with the same figure for the year 1970 (2.7%), this figure shows a significant increase, the relative share of the developing countries is so low that no-one can be sure that this trend will continue in future and that it will not come to a halt or even be reversed. In fact, the high number of factors playing a role in this process, and the different manner in which they act, make any prediction extremely difficult. Nevertheless, given the fact that most of the research done in the developing countries is directed towards the mere subsistence of these societies, that is, towards their survival, one can say that the effective share of these countries in world research is even less than 4%.

To describe this situation, I allow myself to use a term borrowed from economics. A subsistence economy is one in which no surplus production exists, so that all the resources go to the fulfilment of the most primitive needs of the society. Consequently, no idea of growth or development could exist in such an economy. In a similar fashion, we can talk of 'subsistence research' as research whose sole concern is to serve some immediate vital needs of the society in which it is done. Through overcoming some urgent social problems, such research will no doubt pave the way to development, but it is not, by itself, a factor of development.

To give an example, research carried out on the production of a high-yielding crop that can feed more mouths is a great step towards the eradication of malnutrition, which is in its turn one of the great human and social problems of the underdeveloped countries. But a more direct relation is established with the problem of development only when this kind of research does not limit its objectives to feeding people, for example, when a country tries to export the crop produced in this way or when it tries to use its experience to produce other varieties of crops, or even to found an institute to carry out research in plant genetics. Research carried out on a new variety of crop which can feed more mouths belongs to the domain of subsistence research, while research on the production of new kinds of crops, with an eye on potential indirect uses, falls within the domain of what we call 'developmental research', but to carry out research in the field of genetics belongs to a totally different category, i.e. to 'fundamental research'.

It is true that no sharp barrier exists between these three types of research and that a researcher is often obliged to cross the borderline and to pass from one kind to another but, for methodological reasons, we will hold on to this tripartite division. In this way, some difficulties of research in the developing countries are underlined. In fact, a link between research and development is established only when we pass from subsistence research to developmental research. But this transition is not always guaranteed. Certain phenomena, such as population growth, urbanization and social mobility, can have a triggering effect on subsistence research by creating a high demand for every kind of product and service. In this way they can create the first stimuli for research in a developing country. But, at the same time, this can constitute an obstacle for transition from subsistence research to developmental research.

Most of the research undertaken in developing countries in the field of agriculture, food and hygiene products, and some chemical industries, falls within the domain of subsistence research. The researchers and institutions engaged in these activities turn in a circle. For years or even for whole decades, they develop the same product and sell its recipe to the industries that have to satisfy a market always confronted with new demands. Thus, there is a quantitative growth of research, but it is not accompanied by a qualitative one. The dominance of subsistence research is one of the structural problems that beset scientific research in developing countries. A researcher, or a research institute, engaged in this type of research deals with issues which arise from its own society but, from a scientific point of view, these issues are not promising enough to be presented to the international scientific community. They cannot be translated into veritable scientific questions that can be of interest to a larger scientific community. Arising from a given concrete situation, they cannot leave their homeland to join world science.

Subsistence research is one of the two extreme cases we encounter in a developing country. At the other extreme, we find another type of research, which I call fundamental research, i.e. highly advanced research done by highly qualified people. Graduated sometimes from the best universities abroad, these researchers continue their work in the same field in which they did their PhD studies. But, as they find no appropriate structures in their country to support them, logistically they remain dependent on their mother institute, without being able to establish a link between their research topics and the needs, the problems and the general policies of the society in which they live. The results of such research are often published in specialized journals, but they have little impact on the science of their country of origin. This kind of research can be seen as a latent form of 'brain drain', sometimes leading to its more explicit form; as communication is generally difficult and sources and research tools are rare, the researcher finds himself obliged to emigrate to a developed country.

The two problems considered above represent two extreme cases. In one case, the research has a direct bearing on the problems of the society in which it is done, but its application hardly surpasses this limit, and consequently the researcher cannot link the work to the international research network and benefit from such a link. In the second case, the research has a real place in world science, but there is no link between this work and the needs of the society in which it is conducted.

These problems are not due to the personal qualities of individual scientists, but rather to the organization of scientific research in their countries. Most policy-makers of these countries think of science in terms of education. Not being scientists, they consider science as a closed set of knowledge that is produced elsewhere, i.e. in developed countries. All the other countries can do is copy this knowledge and use it, teach it or disseminate it. The idea of the production of new scientific knowledge (that is, of scientific research) has no place within this framework. Nevertheless, the idea of research introduces itself into, or imposes itself upon, this framework. This is done through two channels, each one giving rise to one of the two kinds of research discussed above. In the first place, as was noted before, in their struggle against poverty, malnutrition, diseases and natural disasters, these countries face some problems that demand specific solutions. Thus, the planners are obliged to establish research institutions. Such institutions are often established through a governmental decree before having a clear idea of the society's real scientific capabilities. Thus, they have to train their own research staff. In any case, these institutions have a practical orientation and their domain of activity is generally very narrow. They often suffer from a bureaucratic structure, which is related to their very existence. The research done in these institutions is generally of the kind that we called 'subsistence research'.

Research also introduces itself into the scientific structure of a developing country through a second channel. This is the case of individual research, which begins with the initiative of a scientist or a limited number of scientists, sometimes benefiting from a research institute especially established. This kind of research is generally dependent on a scientific figure and ceases to be done when he leaves. Normally, it has not much to do with the general development policies of the country. In many developing countries, research often oscillates between these two poles. When these countries begin to develop, they give little place to scientific research in their development policies. In fact, the scientific policies of these countries mainly suffer from a pre-modern notion of science, in which scientific research is seen as an individual activity carried out by a single scientist in his library or laboratory, or from a bureaucratic notion, in which scientific research is at the mercy of governmental organizations. In this respect, the case is fundamentally different from what has happened in the West.

In Western Europe, we witnessed a gradual transition from individual to organized research. In fact, when the idea of organized research was born in the West, there already existed an advanced scientific community. This community was based in universities, learned societies and even private laboratories. Thus, some well-defined problems had already taken form. The main concern of those who were interested in these problems was not a utilitarian one, even though the dominant Baconian ideology put the main objective of science as the domination of nature and the welfare of humankind. The transition from individual to organized research took place in this context – a transition that was later to be characterized by the emergence of two new concepts: 'industrial science' and 'national science'.

The emergence of industrial science could perhaps be regarded as the most important single event in the history of the organization of scientific research. The results of this process, which is not yet finished, can be seen in every domain of science and technology. Due to this transformation, technology is no more a set of practical rules transmitted in workshops. Technology is applied science. This is the beginning of what was to be called 'technoscience'. The emergence and the development of industrial science have been accompanied by the emergence of the modern nation state, first in Europe then throughout the world and this has given rise to a second concept: 'national science'.

National science should not be equated with some perverse attempts made to create or reshape science on the basis of the idea of a race, class or nation. It is rather a manner of organizing scientific activity within the framework of a nation state. As there is interdependence between science and industry, and as modern industry is rooted in specific economic and technological conditions of industrialized nations, it is natural too that a strong relation should exist between the development of science and the manner in which the great European nation states were born. Later on, with the advent of planned economies and the dominant role played by the state in this process, science also became an object of planning. It was the state which defined different scientific activities and their relative roles. This pattern was taken over by most of the developing countries. In the absence of a competent private sector, the intervention of the state in the field of science had a salutary effect, but, because of the special conditions existing in these countries, the structure of the scientific network which began to take shape became different from its counterparts in Western countries.

First of all, in most of these countries, the scientific network is an educational one whose principal objective is to train qualified manpower for the state, with research occupying only an insignificant place. Secondly, in most of the developing countries, an independent scientific community is practically non-existent. Research problems are defined by governments on the basis of the everyday needs of society and most of them fall within the domain of subsistence research. Thirdly, research in most developing countries is done by the public sector; the private sector has no interest in research and not even in subsistence research.

In fact, what are lacking in most developing countries are the appropriate structures of research, structures which can locate the actual problems of society and translate them into authentic scientific questions, bridging in this way the gap which exists between what is done in the domain of subsistence research and the vital questions of science. They can, at the same time, provide the necessary link between fundamental research and the development policies in these countries. National research structures try to find appropriate answers to the following simple questions:

- Which domains have to be specified for research?
- What resources have we for conducting research?
- What objectives do we pursue in our research work?
- What are our research needs?

The importance of these questions lies in the fact that scientific development is not feasible without the mobilization of all the century's scientific capacities. But as the number of researchers and research facilities in a developing country is very limited, one is obliged to make a choice. Without appropriate answers to the above questions, any choice would be arbitrary. In many scientific disciplines, effective research is not possible without having passed a certain threshold, without arriving at a certain critical mass, without having a certain number of qualified researchers, and this also puts a limit on our choice. Thus, a good research structure plays a double role. On the one hand, it makes subsistence research scientifically relevant; on the other hand, it makes fundamental research socially relevant, both becoming elements in a comprehensive programme of 'developmental research'. In the ideal case, these structures will constitute a hierarchical organization beginning with the most down-to-earth research activities and extending up to the most advanced fundamental research. We can see that the main problem of the developing countries is neither the kind of research conducted nor its quality, but rather the lack of structural relation between different kinds of research and this manifests itself in the form of a lack of national research structures. It is in this context that we can study the effects of globalization. It is now a recognized fact that globalization is an un-ended process with both desirable and undesirable effects. How a society can cope with these two aspects depends not only on the characteristics of globalization but also on the society in question.

From the point of view of research in the developing countries, we can study three aspects of these effects. The first aspect is the change which globalization produces in the concept of national sovereignty, i.e. in the very concept that is responsible for the emergence of national science. Every national structure has to readjust itself to this new condition and science is no exception. The degree of these changes depends on the strength and flexibility of existing national structures. In societies where such structures do not exist at all, or are too weak or too rigid, the result would be catastrophic. Other societies would take advantage of this situation to change and adapt their existing structures.

The second aspect is the recent revolution in communication technologies. It goes without saying that interactive, real-time communication, as exemplified by the Internet, opens new perspectives for access to information and thus has a tremendous effect on research. But there is another side to this story. The Internet cuts through the traditional structures to reach out to the individual researcher. In the national science model, scientific communication is mostly institutional: each researcher is a member of a university, a laboratory, or a research team, on which he is dependent both for material facilities and for information. The research problems are defined inside these research units and it is through these units that a researcher gets in touch with others working in other units. With the advent of new communication technologies, scientific research, at least in some respects, becomes once more individually organized: a microcosm around a computer, through which the researcher gets in touch with his colleagues, takes part in virtual conferences, has access to new documents, defines and develops new research projects, signs contracts, is paid, etc., etc. Research would be another virtual job. In the absence of appropriate research structures, this would lead to a new, more efficient form of brain drain.

The third aspect is the creation of a world market for research. As this would be a competitive market, even in the domain of subsistence research, the developing countries are obliged to enter into competition with more powerful rivals. To sum up, all recent developments underline the necessity of defining and creating veritable research structures in developing countries. Without such structures, even the 4% of worldwide research will not be maintained. The international community has a great responsibility for creating an international pattern of scientific cooperation to assist the developing countries to develop these structures.

Addressing the socio-economic developmental needs of society: contribution of the geosciences

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Advances in science have contributed, through the years, to the development of every aspect of human endeavour. They have transformed society's way of life on planet Earth, from the food we eat and the houses we live in to the clothes we wear. Progress made in medical sciences, transportation systems, space technology, computers, telecommunications, information technology and genetic engineering are having unprecedented impacts on people's lifestyles.

Developments in basic sciences, in particular physics and mathematics, have also been fundamental for the achievements made in the geosciences which deal with the Earth's basic life-support system – air, water, sea and land. Application of the knowledge of the geosciences has greatly contributed to the protection of life and property, increased food production, improved water use and energy production and consumption, as well as safeguarding the environment. However, several challenges still lie ahead. These include the impacts of natural disasters, food insecurity, freshwater scarcity and environmental problems such as those related to global warming and climate change, ozone layer depletion and transboundary transportation of pollutants. These issues will continue to be important factors in the socio-economic development of many nations during the next millennium.

The expectations of society for science to adequately address these and other relevant challenges are high. Communities affected by tropical cyclones, storm surges, floods, droughts and other severe hydro-meteorological events would like to know where and when such events will occur and how long they will last. The socio-economic impacts of these natural disasters are very significant, particularly in developing countries. For example, in Honduras, two-thirds of the national infrastructure was destroyed following Hurricane Mitch in 1998. In addition, the global economic loss due to the 1997-1998 El Niño events was estimated at more than US$ 33 billion. These examples remind us of the need to improve our monitoring, prediction and warning capabilities to minimize such losses.

In addition, consequences of climate change, such as sea-level rise, would have significant social and economic impacts. Communities and governments would like to be informed of the regional distribution of such impacts to develop and implement appropriate response and/or adaptation strategies. The same could be said of ozone layer depletion. The agricultural sector would benefit from advice on the onset of the rainy season as well as the duration and distribution of the rains. These parameters are of paramount importance for operational activities to improve food production, especially in the developing countries.

Unfortunately, the information mentioned above cannot be provided with the required level of accuracy. Much work remains to be done by the scientific community and, therefore, society should provide the necessary support for this effort.

Nevertheless, the outcome of the Tropical Ocean and Global Atmosphere (TOGA) programme was a breakthrough in establishing a scientific basis for the prediction of climate anomalies for several seasons in advance. However, further development in modelling capabilities is essential for improved climate prediction. This should take advantage of the various initiatives being undertaken within the framework of the World Climate Research Programme (WCRP) and other related activities, particularly those related to improved monitoring of the earth system.

Science for development: the approach of a small island state

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Science and technology (S&T) have shaped our world since antiquity but a new phase began during the 14th century as the development of firearms and the transformation of the sailing ship into a formidable instrument of naval power allowed successful world exploration by European countries. This led to great expansion of the wealth and power of some of these through colonization and trade, and eventually to a number of large independent countries in Africa, the Americas and Asia, and to the little countries of the Caribbean that by their sugar helped provide wealth to fuel the industrial and scientific revolutions. By the end of the 19th century those nations with prowess in S&T had virtual control of the entire globe and, despite the many changes in geopolitics, a measure of this domination continues as the knowledge gap between the developed and developing countries widens.

From the vantage point of the final year of the 20th century, it is clear that scientific growth in the last 100 years has had no parallel in human history. Science has profoundly changed our views of the Earth, the universe and of life itself. Technology has altered most aspects of modern living and promises much more. The knowledge base, capability and capacity of the industrial world, already awesome, is increasing and in some countries already the standards and styles of living, the quality of life and the expectations of the ‘average’ citizen exceed anything that existed previously. For these countries, the early decades of the third millennium promise to be a fantastic period. Consequently, there will be even greater dependence on knowledge and S&T will be even more tightly woven into the existence of people and nations. For some peoples the world will be wonderful; for the ignorant and unskilled the future seems very bleak.

Efforts made in the developing world

This view is hardly new to the scientists or to the leaders of the countries that are now known, sometimes with sympathy, sometimes with a measure of derision, as ‘developing’, South, or Third World. It has long been obvious that the greatest division between the countries of the North and the South is the enormous gap in the theory and practice of S&T. Abdus Salam paid a great deal of attention to this topic and he, like many others in the South, sought to lessen the knowledge gap.

Beginning shortly after their independence, many countries built and supported universities and research institutes, sought to train their nationals and looked to their scientists and others to help shape the creation of wealth and improved competitiveness. Yet, for so many of us it has not yet really come together; scientists often blame politicians and politicians sometimes ask to be shown just what their scientists and technologists have contributed to the bottom line.

Many explanations are given for the difference between levels of achievements in the South and those of the industrialized countries. These include:

- lack of resources;
- the scarcity of scientists, but ironically also the shortage of interesting positions for good scientists;
- the slight integration between the research work of different institutions;
- the difficulty of access to local research data;
- the ‘brain drain’.

These are valid constraints but I think we also underestimated the amount of time and sustained effort necessary to build a scientific enterprise. One thing that has not been lacking is ability, as even a casual survey of the names and addresses of authors of publications and the records of many scientists from the Third World will show. This will also emphasize the benefits that have accrued to the receiving country from the brain drain. Yet it is equally true that the brain drain has provided enormous personal opportunity to our scientists.

Small developing countries

Much of the above is common to the Third World, but the situation can be particularly difficult in the smaller countries where resources in absolute terms are even more limited, as are opportunities, because of the scale of activities. Here, too, the effects of the brain drain are even more significant. While the importance of science is universally acclaimed, each small country must determine just what effort it is willing to make in S&T, in terms of its own appreciation of the intrinsic economic value and overall contribution compared to its numerous other needs. The scientists have a great responsibility in helping lead this debate and indeed in demonstrating by their own efforts that it is a worthwhile debate.

In most fields, a tiny country just cannot compete and therefore a focus on local needs and advantages is necessary. In developing this focus a multidisciplinary approach has many advantages and can support excellent science, of interest internationally also, even within severe constraints, particularly if there is extensive local and international collaboration. South-South collaboration becomes attractive because these countries often have many development-related characteristics and issues in common. One of these is the need for improved knowledge of the total environment – soils, rocks and biota, the surface and underground water, and the coastal areas, where these exist – as a basis for scientific and economic growth and environmental protection.

Jamaica

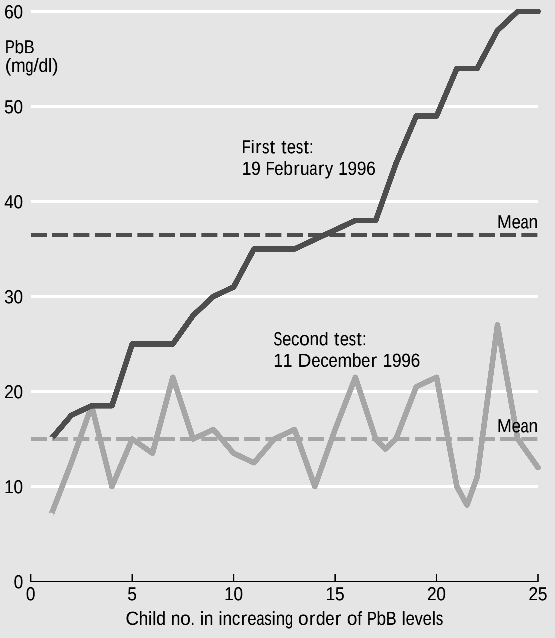
This approach is being carried out in one small country, Jamaica – an island with a population of some 2.5 million and an area of only 10 991km^2 – using environmental geochemistry as the main theme. It depends on a series of investigations with interpretations and applications of both short-term and fundamental value. It aims to:

- contribute to the estimation and management of natural resources;
- contribute to agricultural productivity;
- provide a framework for examination of relationships between trace metal geochemistry and health;
- assist in determinations of land use;
- provide opportunities for fundamental research.

This approach can also help build and retain a critical mass of workers, reduce the impact of the brain drain, strengthen collaboration with national scientists resident abroad and enhance international cooperation. This may appear overly ambitious, so an example is worthwhile.

A regional geochemical mapping in Jamaica identified a poor community that was seriously contaminated by the operations of a lead/zinc mine in the last century. The school for four-to-six year-olds occupies a building which served to process the mine ore and the very high concentrations of lead in the schoolyard are reflected in the blood lead levels in the upper curve of Figure 1. The lower curve presents the results for the same children eight months after a simple intervention consisting of isolation of the lead in the playground, education and food supplementation. The interventions have led to dramatic reductions in blood lead levels, some by factors greater than three, towards the lowest band which represents the recommended limits of the US Environmental Protection Agency.

Figure 1. **Blood test results before and after intervention**



This example illustrates a number of the points referred to above and emphasizes how work within the chosen research theme can be of immediate value. This particular study area might be of wider interest because it involves a population that has been exposed to high lead concentrations for nearly 50 years. There are numerous other possibilities, partly because the environmental geochemistry of the tropical regions has been so little examined in comparison with the temperate lands. International collaboration should assist in the national programmes of, and provide specific information of interest to, the participating countries, and the combination of information from each country would contribute a global viewpoint similar to that of the Global Geochemical Baseline Project of the industrialized countries. Such collaboration could be the basis for joint resource exploitation and environmental collaboration.

International collaboration

South-South collaboration in areas such as these presents several opportunities partly because of need, but also because there is so much to be done in the tropical regions that can be of significant mutual benefit. Several institutions, including the Third World Academy of Sciences, have been encouraging South-South collaboration; and among the several opportunities is a network of international centres of excellence set up as a result of the resolution by the Heads of Government of the Non-aligned Countries in 1989 to support S&T in areas of critical importance to the countries of the Third World. Consequently, a Commission on Science and Technology for the South (COMSATS) now exists with a centre in each of: Bolivia, Brazil, the People's Republic of China, Colombia, Egypt, Ghana, Jamaica, Jordan, Nigeria, Pakistan, Syria, United Republic of Tanzania and Turkey. This network, in conjunction with the Third World Academy of Sciences, UNESCO and other United Nations bodies, development banks, foundations and other institutions, can be a powerful influence to assist the scientific community in the South and to encourage increased North-South collaboration.

Conclusion

Despite various constraints, small developing countries require S&T to assist in their socio-economic development but certain decisions are usually necessary to achieve the desired impact, which includes convincing the political leadership that the investment is essential. An excellent mechanism for achieving this, maintaining a critical mass of scientists and providing for the best use of resources appears to be to ensure excellence in a limited number of multidisciplinary themes based on areas of particular need and the strengths of the country. Such programmes are also excellent vehicles for South-South cooperation, both bilateral and through networks of centres, one of which, COMSATS, already has 13 members worldwide.

Building capacity and creativity in science for sustainable development in the South

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It is extremely difficult to address a thematic issue on building capacity and creativity in science for sustainable development in the South in 10 minutes. Therefore, I shall be handling my presentation in terms of flashes (with transparencies) to highlight the main points.

As we stand on the threshold of a new millennium, it is clear that science is at a turning point. All countries have to face important decisions regarding the conduct of science and technology. Better-endowed nations have to rethink their science priorities in the face of economic, political and ethical challenges, while developing countries have to strive to build the critical capacity for effective research and development (R&D) leading to development. The countries in socio-economic transition have to replan their science without discarding valuable assets from the past.

The current century has been characterized by an explosive growth of information and knowledge gained through scientific research. As a result of the technological application of this knowledge, we have witnessed the evolution of new materials, informatics, communications, biotechnology and electronics. The 20th century has been the atomic age, the new biology age, the space age and the age of understanding the organization of the universe.

The major driving force behind high expenditure on science during the 20th century was mainly military enterprise, two World Wars and a very long Cold War, which have led to mega-science in information, communication, electronics, space and aerospace technology and many engineering and energy fields. Another force in the advancement of science was intellectual competition in a free environment for scientific discoveries and publication in universities and scientific institutions under the motto ‘publish or perish’, led by a sense of curiosity and competition for promotion.

The breakthroughs in modern science have left their mark on humanity. One is in nuclear fission, which has led to prosperity in nuclear energy and its application but also to man-made disasters. The second is the unfolding of the spiral DNA, breaking the genetic code, and its impact on applications in medicine, pharmaceutics and biotechnology, and also the ongoing series of discoveries in genetic engineering. The third breakthrough was in hardware and software R&D in computer and information sciences, which gave birth to the information revolution.

Throughout history, academic institutions contributed to breakthroughs in scientific achievements. This process was led by the curiosity of scientists and the intellect of minds. Science has always been universal and new knowledge has flowed freely across the frontiers of the globe. With the birth of the market economy, new knowledge became extremely important for commercialization. Patents of innovations transcribed from new knowledge started to expand at the expense of free access to knowledge in literature. There was a cap placed on new knowledge as a result of contractual growth in patenting.

With the expansion of the free market economy in the years 2000+, a growing trend towards secrecy in research is expected and more basic research will be financed by the private sector. This will curtail publication for free dissemination. This may widen the gap in knowledge and in access to information between the industrialized countries and the developing countries.

The main trend revealed by the UNESCO *World Science Report 1998* is one of continuing asymmetry in the way science is distributed around the world. We see that all the developing countries taken together are responsible for a mere 10% of total gross expenditure on research and development, while the member countries of the Organisation for Economic Co-operation and Development (OECD) can claim 85%. The industrialized countries commit between 2% and 3% of GDP to R&D, whereas the countries of the South only manage a fraction of this. In Latin America and Africa, for example, the investment ratio is generally 0.4% or below. Even countries with important scientific communities in certain disciplines, like India, Brazil or China, are not able to devote more than 0.9%.

The pattern is repeated if we take the numbers of active scientists and engineers. Although some 25% of scientists are found in the Third World, the regional figures again show a striking imbalance. While the European Union supports two scientists per 1 000 population, the USA 3.7 and Japan 4.1, the developing countries have much more modest levels – for example, sub-Saharan Africa has less than one-tenth of the Japanese value.

Nobel Laureate Abdus Salam made the comparison: ‘in 1990’, he said, ‘there were 3 600 scientists/engineers per million population in the industrialized world. In Israel and Japan, the figure was 5 500. But when we look at the Third World, there were only 200 scientists/engineers per million population. Also, the critical mass is lacking. Adult illiteracy is a major obstacle to S&T development.’

Nobel Laureates are produced in the laboratories of the West. Even those from the Third World have succeeded while working in the industrialized countries. Basic research and training have been established in a variety of engineering disciplines precisely to train technological problem-solvers to integrate knowledge from various disciplines in the development and use of complex technological systems and to identify practical problems, the solutions to which require more fundamental scientific understanding.

Out of the 61 million students in the world, 2% study in foreign countries. Of these, 70% come from developing countries. Sub-Saharan Africa sends the biggest proportion (14%). The USA receives over one-third of all students studying abroad; nearly 3% of all students in the country. An even greater proportion of postgraduate students in the USA come from abroad: 28% of all graduate science students and 47% of engineering students.

The challenge to the South is how to convert ‘brain drain’ to ‘brain gain’. Scientists in the diaspora have established their roots in a more fertile soil abroad, but many branches could shed their fruits in the mother land. This may be achieved through connections, joint seminars and workshops, Internet and e-mail, networks of scientists abroad and at home, scientific visits of short duration for lecturing or for partial supervision of graduate students, visiting professorship schemes, UNESCO chairs and UNITWIN in universities, databases and information systems, joint supervision of research graduate students and networking through university satellites. TOKTEN schemes may bring national expatriates back for short periods to their original homelands to transfer and share the knowledge they have gained. Communications and the Internet have made people live closer together by enabling them to speak daily with each other.

It is clear from these few examples that, for many parts of the world, two things are needed: firstly, a clearer commitment to science by governments and politicians; and, secondly, a broad investment in capacity-building – the strengthening of scientific infrastructure and the development of human resources in sciences.

By the same token, governments everywhere are seeking ways to tie in more closely investment in research with economic and social goals without endangering the fundamental research that is the basis of tomorrow’s innovation. This is not easily achieved and great care needs to be taken to ensure that the balance between pure and applied research is not distorted. ‘There can be no applied science if there is no science to apply.’ (Bernard Houssay)

Another challenge for scientific advancement in the next millennium is the issue of ethics, in particular bioethics. Ethical questions have already surfaced on the biodiversity of the human genome. Ethical and property rights will be encountered in the field of genetic engineering and biotechnology. Ethics provide the framework and reference to help society take responsible decisions about issues affecting their lives at the present and future time; to safeguard our heritage, whether cultural, natural, genetic or non-physical, for future generations.

The subject of scientific literacy is central to many of the issues and themes. Professor Francisco Ayala (UNESCO *World Science Report 1996*) argues that scientific literacy is necessary for there to be a capable workforce, for the well-being of the social fabric and the well-being of each individual and for the exercise of participatory democracy. Science and technology have changed the world we live in and will surely continue to do so. What we must ensure is that each member of society – young or old, rich or poor, man or woman – has enough understanding of science to be able to assess the arguments advanced by experts or decision-makers and understand the economic, ecological or health consequences that might follow. The productive sector of the economy demands a labour force that is scientifically literate. Workers are required to understand complex instructions in order to operate equipment and to understand the vast information disseminated by the mass media about technological matters. Scientific literacy is needed at home to operate electrical appliances and to enjoy the fruits of science discoveries. So what is needed now is to include in this literacy programme a component in scientific literacy and environmental awareness. Just being able to read and write is no longer sufficient to cope with the complexity of the world in the next millennium.

Strengthening science, mathematics and computer technology from an early age

Breakthroughs in brain research have led to understanding of human behaviour, of the mental mechanism and the learning process. The human brain has a very large unused potential of 90%. Conversely, given the current cerebral biochemistry and the brain's 10 000 million neurons, the human brain of the child could develop its creative capacities to unimaginable limits. All languages have to be taught at the pre-school and primary school levels to build the microchips of the brain as 'acquiring' and not 'learning'. Three or four foreign languages could be 'acquired' by the child in his early childhood together with his native language. This will expand the pupil's vocabulary and open his memory to new horizons. The old concept of 'we're overloading the poor child' is no longer valid. Motivation to study science and mathematics should take place in early childhood, injecting technology to make the educational model more efficient, equitable and cost-effective, and to develop restructuring of the mode of inquiry and problem-solving. Globalization of technology is to communicate, calculate, make an intelligent decision and innovate. Computers in terms of hardware and software should accompany learners from their childhood and throughout their entire life. This is how to build information technology and management of information as an inherent component of the individual brain. Information technology is the force that revolutionizes business, streamlines government and revolutionizes operations. We have to start restructuring our schools, to go from low-tech to high-tech schools. This obviously requires a new vision for the retraining of teachers so that we can improve the education of students.

Transforming education for a knowledge-based society

Multimedia software is becoming creative and it is possible for users to navigate across a broad spectrum of topics and to go into these topics in depth. The possibilities which computers offer as a tool to help students to learn, to construct knowledge and to comprehend, constitute a true revolution of the learning process and an opportunity to transform schools. This transformation goes much deeper than simply installing a computer as a new educational tool. Computers must be inserted into the learning environment to allow 'construction of knowledge', comprehension and development of capabilities that are necessary to function in the knowledge society.

Building human capital for the information age

Schools and universities must change to meet the challenges of a knowledge-based economy in the information age. New skills are needed for the emerging information-age workplace. If students are to become intelligent users of technology and information, they should also learn how to be creative and innovative. They should be involved in problem-solving and research and should be able to tackle case studies and understand how to analyse data and draw intelligent conclusions.

Education faces the daunting challenge of preparing individuals for the information-age society by teaching them:

- how to manage an avalanche of information;
- how to prepare the most efficient human capital for the brain-intensive marketplace;
- how to prepare flexible human resources to meet the uncertainties of a global economy;
- how to innovate to keep up with a high-speed, knowledge-driven, competitive economy in the workplace.

Relevance and quality of teaching and research

Investments in higher education and national research and development are increasingly seen as key components of economic growth and poverty reduction strategies based on successful technological accumulation. The economic contribution of higher education and research is both direct and indirect. First, there is a direct impact whenever university-based research leads to industrial innovation. Second, there are indirect, though no less important, effects through the training of qualified managers, scientists, engineers and technicians who participate in the development, adaptation or diffusion of innovations in the productive sectors. It is recommended that investment by both public and private sectors in developing countries in education (all education) fall within the range of 6% of GDP. Investment in scientific research in R&D by both the public and private sectors should fall within the range of 1% of GDP. Science parks and incubators to apply university R&D and turn it into technological innovation should be created.

Freedom of expression, human rights and democracy-building

Democratic institutions free of red tape and bureaucracy are needed to provide an inducing environment for the release of the maximum creative and innovative potential of individuals. The South is in bad need of entrepreneurs.

European Union research programmes with linkages to development

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International collaboration in research, involving universities, research centres and industry, has long been supported by the European Union (EU). It has been organized since 1984 within successive multinational framework programmes. Community research activities are designed to complement those of the EU's Member States and work towards closer integration of Europe's scientific and industrial communities. The central objectives of Community research policy are to reinforce and mobilize the Union's scientific and technological capabilities in support of industry, the economy and quality of life.

The Fifth Framework Programme (FP5, 1998-2002) breaks with tradition in targeting resources on specific socio-economic objectives, by means of focused research actions of an integrated and interdisciplinary nature. The approach is more selective than the science- and technology-driven approach of the past and will favour partnerships and networks of research actors – public and private – which are more strongly oriented towards utilization and uptake of results. Structures for implementation will allow more flexible allocation of resources to follow changing priorities. These changes should ensure that research efforts undertaken are effectively translated into practical and visible results.

In contrast to the disciplinary structure of the Fourth Framework Programme, involving some 20 separate specific research programmes, the Commission has proposed a Fifth Framework Programme, organized around seven individual programmes which include four thematic programmes and three horizontal programmes, with a budget of Ecu 14.96 billion over four years.

The four thematic programmes cover life sciences and biotechnology, user-friendly information technologies, competitive and sustainable growth, and energy and environmental questions. They combine a focus on a limited number of objectives, through interdisciplinary, integrated 'key actions', with actions to maintain and strengthen the science and technology base.

The horizontal programmes complement the thematic programmes by focusing on issues of international cooperation; small and medium-sized enterprises (SMEs); dissemination and exploitation; training and mobility. These actions are common to all thematic programmes but require also coordination and complementary specific activities.

In the emerging multipolar world, geopolitical and geo-economic challenges require a concerted application of the relevant EU instruments: Development Cooperation, Economic Cooperation and S&T (science and technology) Cooperation. The EU intends to ensure a coherent and strategic application of these instruments to maintain Europe's international presence in a knowledge-based society. It is a society in which economic competitiveness depends entirely on the ability to promote knowledge systems internationally.

Within the emerging region-to-region cooperation patterns, cross-policy orientations are evolving in the EU. An evolution is taking place in the Union's Development Cooperation policies in relation to developing countries and emerging economies to move away from traditional aid towards more trade-oriented relations which would be mutually beneficial, without disregarding humanitarian and poverty alleviation concerns. Economic Cooperation policy has seen a growing trend in support of human and institutional capital development, with the aim of bringing together the knowledge systems in the Union and those in developing countries and emerging economies (e.g. cooperation between universities, private-sector federations, etc.). Closer cooperation in regional S&T arrangements is also under way (ASEM, ASEAN, MED and possibly others).

As the main foreign direct investor, the largest world market and the biggest purveyor of development aid, the Union is poised to play a major geo-economic role in which the Research and Technological Development (RTD) policy will be instrumental in mobilizing S&T resources to reinforce pro-actively European international competitiveness. The resources of FP5 are being mobilized to address the following main groups of issues:

- the role of the EU in equitable economic growth including our contributions to quality-of-life issues such as global food security and health care as key elements in regional and global solidarity and security;
- tradeable goods and services, emphasizing development and quality assurance based on accepted international standards, including environmental and social accountability aspects;
- environmental conservation and sustainable natural resource use for an enabling and demographically stable

human environment. This relates also to the Union's international commitments and interest in jointly and safely promoting the economic and ethical use of biological resources;

- based on policy research, the generation of policy options for decision-makers concerned with the twin goals of promoting knowledge-based development as well as the integration of developing countries in the world economy.

Thematic meeting report

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Science and development have been closely linked since the dawn of the industrial revolution, if not before. As a result, no one should have been surprised to hear participants in this thematic meeting declare that the ties between these two forces have never been closer as we approach the dawn of the next millennium.

The meeting, organized by the Third World Academy of Sciences (TWAS), devoted a great deal of discussion to the role of society, which nurtures scientific research and is critical to its success. This role, if neglected, spells trouble for the scientific community, especially in the developing world where scientific research is often not widely appreciated by the general public.

That is why many of the participants maintained that developing nations must invest in education – not only science education at university but equally important general education at the primary and secondary levels. C.N.R. Rao, for example, suggested that each developing nation should strive to invest 6% of its annual gross domestic product (GDP) in its educational system, a percentage comparable to that of developed nations.

Why is it so important for this investment to take place? First, an educated citizenry is essential for the long-term support of science. As an increasing number of developing countries embrace democracy, it is essential for them to solicit public support for their scientific agenda and that support is more likely to come from well-educated citizens than from poorly educated citizens. Second, students at the primary and secondary levels provide the pool from which a nation's future scientists are drawn. In short, an uneducated citizenry today will likely translate into too few scientists tomorrow. Third, science, as several participants pointed out, has become the universal language of the 21st century. If a nation fails to speak the language of science, its illiteracy will confine it to the sidelines of the international economic arena.

Beyond education, another fundamental prerequisite for building a strong scientific community is a stable political structure led by public officials who appreciate the close relationship that exists between science and development. As Adnan Badran pointed out, science is a long-term enterprise that does not fare well under policies that unfold in fits and starts. For this reason, he urged each developing nation to set a goal of investing 2-3% of its annual GDP in scientific research and development (R&D) – a percentage comparable to R&D investment levels among developed nations. Participants acknowledged that the governments of developing nations face a daunting inventory of economic and social problems demanding immediate attention and rarely have the financial resources to fully address their citizens' most basic needs. Nevertheless, participants contended that the cycle of poverty and hopelessness that now plagues many developing countries can only be broken if a nation makes a solemn long-term commitment to enhance its scientific capabilities.

Participants noted that powerful new tools are available to help developing nations in their science-building efforts. On the administrative side, several participants, including Ahmad Jalali, cited the importance of South-South and South-North cooperation for advancing the scientific agendas of all developing nations. Several developing countries – for example, Brazil, China and India – now enjoy strong scientific infrastructures. These nations have acquired a great deal of knowledge not only in science but also in science policy and administration. Other nations in the developing world could learn much from their experience. Moreover, 'less developed developing nations' have also acquired a wealth of experience, for example, in projects designed to increase crop yields, improve public health and upgrade drinking water and irrigation systems. Sharing these experiences would allow developing nations to learn from one another, possibly providing valuable signposts for shortening the path to science-based economic development.

Thus, all Conference attendees agreed that networking is important. Mohamed Hassan highlighted the work of the TWAS and the Third World Network of Scientific Organizations (TWNSO) – most notably, the publication of the recent monograph, *Sharing Innovative Experiences* (in cooperation with the United Nations Development Programme) – as an example of an initiative that could have a forceful impact on the future of science and technology in the developing world. He called on international institutions and aid organizations to fund additional projects like this and expressed support for the World Bank's recent decision to sponsor millennium institutes of scientific excellence to help anchor and advance scientific research and development throughout the developing world.

If networking, information exchanges and centres of excellence offer hope for building the appropriate frameworks for strengthening scientific capabilities in the South, then the new information technologies, particularly the Internet, hold the promise of warp-speed advances in the distribution of scientific knowledge. The ability of developing nations to grasp and utilize these new technologies, several participants noted, would serve as a critical prerequisite for scientific progress in the developing world. Why? Because new information technologies provide a way for developing nations to make up a lot of ground in a brief time. Conversely, if the developing nations fail to keep pace with the new information technologies, they will surely fall farther behind, given the accelerating pace of global scientific research and development.

The long-term health of a nation's scientific research enterprise depends on scientific literacy, scientific awareness and the public understanding of science. It also depends on how far scientific research succeeds in meeting the needs of society. For example, participants acknowledged that scientists must address real-world problems. That does not mean that basic science should be treated as a stepchild but it does mean that science at some point must be concerned with issues that are of critical importance to people: food security, water quality, waste management, energy supplies and resource conservation. Only by addressing such issues will scientists garner the public support they need to succeed. And only by mitigating the problems associated with critical public concerns will sympathetic government officials have the ammunition they need to seek larger budgets for such scientific endeavours.

Such a strategy also suggests that science must be closely linked to technology. Again, this does not mean that basic science should be ignored but it does means that possible 'worldly' applications of scientific inquiries should often be considered from the beginning of the research process, not as an afterthought. As some observers have argued, scientific applications sometimes take place as a result of serendipity. More often, however, they are products of careful planning and the consequence of close ties between science and such related fields as engineering, agriculture and water management. Just as the lines of demarcation between theoretical and experimental physics have blurred over time (with avenues of inquiry in one justifying and amplifying analyses in the other), the lines of demarcation between basic and applied science have also blurred, creating a productive environment in which each form of inquiry has an opportunity to learn from the other. In short, the linear notion of 'science then development' has been transformed into non-linear notions of 'science and development'.

All this means that scientists, particularly in developing countries, will increasingly shoulder additional social responsibilities beyond their existing commitments to excellence within their professions, which can never be compromised. In return for these commitments, the governments of developing nations owe it to their scientific communities to treat scientists as 'precious commodities', providing them with adequate pay and good working conditions. Unless such basic factors are addressed satisfactorily, participants warned that the insidious impacts of the brain drain would continue. As they have for the past half-century or more, scientists from the developing world would migrate to developed countries where their prospects for personal and professional satisfaction would remain far brighter than their prospects at home.

Finally, participants noted that developing countries would have to attend to international legal issues to prevent their resources from being exploited by multinational corporations in the North and, at the same time, to ensure that the fruits of science in the next millennium do not become the exclusive property of the rich. Thus participants warned that developing nations must actively join the debate over international property rights to protect both the environmental integrity and potential commercial value of the cornucopia of biodiversity found in their countries. In addition, participants urged developing countries to join this debate to ensure that corporate ownership of new seeds, made more productive through the applications of genetic engineering, does not force farmers and consumers in the developing world to become beholden to huge agribusinesses headquartered in the United States.

In conclusion, the session on Science for Development held at the World Science Conference focused on broad policy issues that will likely determine the health and vitality of the scientific enterprise in developing countries in the years and decades ahead.

The feasibility of science foresight: what are the priorities?

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Common sense dictates that any science forecasting exercise should be approached with a prudent degree of scepticism. How can we hope to forecast developments in science when the discoveries of the 20th century have been a series of such extraordinary surprises that even specialists think that they would have been totally impossible to predict?

What is more, some of those discoveries – relativity, wave mechanics, the genetic code, fractals and undecidability theorems, for example – have radically transformed the way we see things. They are paradigm shifts that affect not just one specific area of science, but the public's perception of the most fundamental questions: the origin of the world and the nature of life.

Some groups of scientists have nonetheless attempted to outline some future developments. In some cases, where a discipline-by-discipline approach has been taken to foresight exercises, they do no more than relay their colleagues' consensus view of the future. In so doing, they are expressing the contemporary viewpoint of 'normal science', in Kuhn's sense of the term, precisely the viewpoint which new and original ideas will challenge.

We should add, too, that over the past 50 years science has become institutionalized. Today, enormous sums of money are at stake. Consequently, much of what we hear about the future of science, especially from those directly concerned, is far from disinterested and that is precisely where the problem lies. Often, so-called 'foresight' exercises are no more than a series of 'self-serving' arguments aimed at putting the case for one discipline or another rather than at taking an objective look at trends in knowledge.

Two qualities are essential in any attempt to forecast developments in science. The first is the ability to keep a totally open mind and to be completely unswayed by the influence of any scientific lobby. The second, and the most difficult, is to have an understanding of the factors that will shape the development of the sciences and a clear vision of how to put them in perspective.

For that matter, there is more than one way of viewing the development of the sciences: after Kuhn, we could mention that of Gilles Gaston Granger, who was interested in the 'styles' of scientific approach, or that of Bruno Latour, who compared the epistemology of social groups in different societies. For Latour, the cognitive behaviour exhibited by biologists resembled that of any other 'tribe', from aborigines to corporations.

Interesting as these views may be, they still do not provide us with a basis for forecasting developments. In what follows, I do not claim to solve the problem. I merely point to some avenues that may lead to a 'rational account', as ethnomethodologists would say, of science in the future.

The first point I would like to make is that modern technology is generally considered to be the daughter of science. But technology is also the mother of science in that all sciences depend on a single technology, namely metrology. The Hubble telescope and large particle accelerators are measuring instruments. Pasteur's biological research required the use of the microscope. Modern biotechnology is dependent on measuring and calculating instruments that enable us to identify proteins and the genome. Measurement is the basis of science and the indispensable instrument for confirming the validity of theories.

In fact, for two centuries, metrology has always advanced in the same direction: greater precision and greater complexity. It has produced more than just measurements. It has also enabled us to see hidden structures (ultrasound and thermography, for example) and to record movement (video, fast-scan cameras, stroboscopy, etc.). Assisted by these new tools, the development of new disciplines such as ethology (the study of animal and human behaviour) has been enhanced and accelerated.

Moreover, the most recent advances in measuring time, particularly those by Nobel Prize winners Chu and Cohen-Tannoudji, offer hope that advances on a similar scale will be made in the measurement of many of matter's most intimate phenomena. For example, we can conceive of measurements to the nearest femtosecond (10^{-15}), which will enable us to film chemical reactions (femto-chemistry), including reactions in living matter. Similarly, arranging molecules to build computers or robots the size of a pinhead, for example, is another possibility.

It is also possible that the completion of ongoing studies on 'decoherence' will resolve the conflict between relativity and wave mechanics. This will not just be a theoretical breakthrough. Once the wave-like nature of all physical matter, including ourselves, is clearly established, our representations of the world around us will inevitably change.

This should be seen in relation to changes in technology and society as a whole. Our foresight exercise, which involved hundreds of researchers in the 1980s and 1990s, reached one key conclusion: we are witnessing the beginnings of a new global technology system. In other words, there will be a lot more than just a few inventions. We will see a system-wide transformation that will affect every technology. The previous transformation was the Industrial Revolution, which was accompanied by an upheaval in our social structures and culture on a scale that the world had not seen for more than 500 years.

What is in store is change on a similar scale. Just as in the 18th and 19th centuries, Europe evolved from an agrarian society to an industrial society, we believe that in the coming century the whole world will change from an industrial society into a cognitive society. Why ‘cognitive’? By analogy with the cognitive sciences, which will be central to future research. These are the sciences that study cognition as a phenomenon and as an area of research. They are based on neurophysiology but also involve information technology (can we simulate cognition?), ethology and linguistics. They also have much closer links with philosophy than in the past (what is knowledge? Socrates’ ‘know thyself’).

Why should the central role given to the physical sciences in the industrial society now be taken over by the cognitive sciences? The answer is because the nature of work and employment is shifting in exactly that direction. In industry, employees attend to machines. They feed raw materials into them and monitor their real-time operation. As the cognitive system becomes more established, industrial plants have fewer and fewer workers. Employees simply attend to other machines, machines for communication or even programmed machines (robots), which are replacing the workers of earlier times.

The essence of technology, as philosophers would say, is changing. In 1953, Heidegger, at the height of the industrial society, wrote that the essence of modern technology (at the time) was ‘*ge-stell*’ or ‘standing reserve’. Under the pretext of meeting the needs of mankind, nature was used as a standing reserve and, in order to exploit it, man was used in the same way. A contradiction arose because man felt no need to serve as a standing reserve, explaining Heidegger’s assertion that man was not the master of technology. On the contrary, man was, in a way, collectively shaped by the essence of technology, ‘*ge-stell*’, or ‘standing reserve’.

To me, it seems that the transition to a cognitive society is being accompanied by a change in the essence of technology. In the era now approaching, the essence of technology is no longer a ‘standing reserve’ but ‘pro-gramming’, or, according to the etymology of the word, ‘writing in advance’. Indeed, microprocessors can perform operations in only nanoseconds (with tomorrow’s optical computers, in femtoseconds), which is much faster than neurons can process information. Therefore, inevitably, people will have to programme computers and ‘writing in advance’ will become the determinant of the essence of technology.

I should add that the mechanisms of living things also fall within the ambit of ‘pro-gramming’. A genetic code is a program. The analogy with computers is so striking that the phrase ‘computer virus’ was soon coined to describe parasite lines of code capable of reproducing, breaking through hostile defences (analogous to immune defences) and causing substantial damage in the memory of their computer host.

While the industrial system was based on the twin components of matter and energy (we know since $E=mc^2$ that they are one and the same thing), time/living organism will be the twin components of the cognitive system. Computers are compressing time-scales (to nanoseconds and soon femtoseconds) and in the 21st century will approach the speed of living functions, to such an extent that we can already foresee the possibility of creating ‘intermediate’ (neither animate nor inanimate) entities, as announced by Philippe Quéau in *Métaxu*. He saw in his creations a new form of art and also, probably, of combat.

Upstream of the industrial system was mining, the extraction of raw materials for processing by industry. Upstream of the cognitive system is metrology, the collection of data to be processed by cognitive processes. Industry is about production, aimed in theory at meeting the needs of man. The cognitive system is completely different. It is about consciousness and aims at meeting quite different needs, first, but not solely, the need for knowledge. Hence, the role of science, which in this case goes far beyond providing support for industrial progress, becomes more socially important.

In this regard, I will mention only one fact to help understand the relationship between changes in scientific paradigms and changing outlooks, as historians would say. We have known, since Watson’s discovery of the genetic code 30 years ago, that life from ‘the amoeba to the elephant’ (J. Monod), and of course human life, is one and the same phenomenon.

The fact is that, for thousands of years, religions and philosophers have been tirelessly repeating that man is a being apart, whose innate superiority to animals gives him dominion over nature. This view, still predominant today, is being covertly refuted by science. The new vision has a steadily growing public voice. What we are seeing is the slow but inevitable rise of so-called ecological concepts, the only really new political trend in the latter half of this century.

However, it is also inevitable that science apply to itself the paradigms that it has created. Probably some time will be needed for the new ‘world vision’ to percolate through to other disciplines and be absorbed by the body of society as a whole. To get some idea of this, we simply have to examine the successive interpretations of the Darwinian paradigm in economic, social or even scientific (Latour) ideologies, for example. Liberalism and socialism both laid claim to Darwin, demonstrating that even opposing social principles are necessarily based on the dominant interpretation of life.

The cognitive paradigm should be understood as including both what we call the cognitive sciences and the innermost mechanisms of living organisms, along with the exploitation of the potential of the genome, immune defences (which, as Varela noted, are the starting point for recognition and consequently for the cognitive) and the as yet little-known processes for ‘reprogramming’.

This paradigm contains the seeds, in my view, of the end of scientism. Indeed, the implicit assumption is that science, as we know it, is one vast abstract subject in which knowledge is accumulated. It is this subject that scientists are referring to when they say ‘it is known that… it can be said that’ or even ‘it cannot be said that’. Thinking about it, it seems to me that the vantage point from which the scientific community is speaking (its use of the impersonal) is like the last avatar of the concept of an omniscient, but relativist, God, since the knowledge in question is ‘falsifiable’, to borrow the epistemologists’ term, in other words, can be refuted by experience.

The cognitive paradigm should be able to refute the notion of one vast subject by basing itself on a real principle: there are several subjects. The difficult part is to find out the common denominator between what these different subjects perceive and how they communicate. From that point on, entire universes of beliefs and influences, which we had been accustomed to keeping at arm’s length, become part of science’s domain. Science must see itself as an emanation of life and derive its value from serving life.

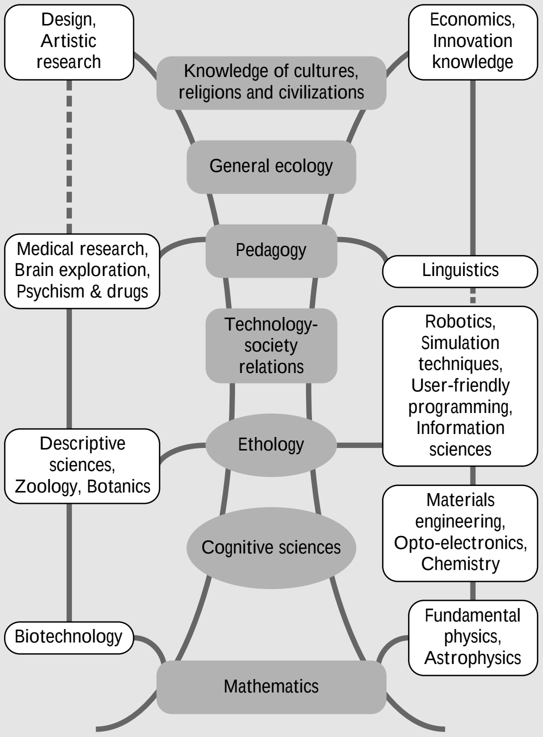
In the 20th century, there was too much science without ethics. I foresee that, in the coming century, scientists will have to debate ethics and prove to the public that they adhere to ethical principles. Those who fail to do so may even run the risk of finding themselves facing legal problems.

Given the foregoing, the position that science holds in society can be expected to change. The 20th century was the century of World Wars, including the Cold War. The field of science concerned worked under the seal of confidentiality. Science as a whole maintained a distance between itself and the public, whereas in Pasteur’s time both had been very close.

Recommendations

- Every effort should be made to bring science closer to the public, by disseminating knowledge and also by choosing research subjects that are closer to everyday life. The cognitive sciences should be given their rightful place and conclusions for education should be drawn from them. Measuring and testing systems for the needs of everyday life should be developed worldwide: consumer and environmental protection, metrology for small businesses and the self-employed.
- It has become apparent that multinationals increasingly tend to appropriate essential constituents of the future economy through patents or authors’ rights, namely software, which has become de facto standard, or genomes. Researchers and legislators will have to help the public and

Figure 1. **The future of scientific research**



small businesses to free themselves from such abuses of the law and of dominant position.

- Lastly, it would be advisable to foster research and discussions on ethics and science on every continent of relevance to the civilizations living on each continent, in the context of both the present and the future.

Annex

The ‘knowledge tree’ illustrated in Figure 1 attempts to show the future shape of scientific research in the next century. The transformation of the current system of technology will also transform the research landscape.

The first prediction that we can make is a qualitative increase in precision and complexity. Precision as regards time: measuring time down to the femtosecond and the development of femto-chemistry, for example, which will open up the possibility of being able to view elementary chemical reactions such as those generating proteins in our bodies and the possibility of constructing computers out of suitably arranged organic molecules.

The corollary of this forecast is a parallel increase in complexity, which radically undermines the former paradigm of science itself. The 20th century has demonstrated the limits imposed by the nature of language on theory and calculability (Gödel and Türing). The trend in the coming century should be towards overcoming this apparent obstacle by developing holistic but rigorous intellectual approaches centred on the cognitive sciences, ethology, descriptive sciences and simulation techniques.This ‘classification’, which will be modified and improved, is shown as a tree as a reminder that science grows, as does every manifestation of life, from the bottom up like a bush unfolding its leaves to the energy of the sun.

Setting priorities in a new socio-economic context: an industrialist’s view

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The failure of the linear model

Scientific knowledge provides options for our future. Present trends involve the risks of short-termism in industrial research and development (R&D) as well as in government-sponsored research. At the same time, the borderline between research and industrial policy has been blurred and we are faced with two paradoxes.

Greater investments in research will not necessarily result in more jobs. In the long term of course, the increase in our standard of living has been and will be dependent on technological progress, but it is difficult to prove a direct correlation between the resources used locally on research and local growth. This apparent paradox has two explanations: first, scientific results spread rapidly. Secondly, it is the capability to utilize results which is decisive, not just the achievements of the results. Research is only a small part of the innovation process, and of the process of bringing science to business.

It is true that scientific discoveries have led to technological developments. But there are several examples of developments in industry creating the basis for science. So, instead of a linear model, technology and science develop in parallel. Moreover, the biggest fraction of innovation is related to incremental improvements and these take place through an intimate collaboration with customers and suppliers. For the industrial companies, the innovation process is the management of knowledge irrespective of its source and the build-up of the necessary competencies to turn this knowledge into business.

Trends in industrial R&D

Industrial research activity has changed significantly over the last decades. Many companies, especially large ones, have chosen to focus on ‘core business’ and ‘shareholders’ value’ and have consequently cut down their R&D activity significantly. This has endangered their long-term view, which should provide the basis for renewal and maintaining competitiveness. Companies try to solve this in various ways.

One solution is to outsource the long-term research to public research laboratories, many of which, of course, are hungry to undertake research contracts. Another result has been that room has been created for many smaller high-tech companies being strong in a special technology niche.

However, there is a limit to how much can be outsourced. A company must maintain its core competencies and its ability to monitor and adapt new knowledge.

The R&D effort cannot be evaluated merely from the perspective of the planned financial return. The Net Present Value (NPV) of the business plan to the company over the total product life-cycle may easily be misleading. The value of long-term research is the creation of future options and hence the flexibility of the company to respond to uncertainties in a rapidly changing world.

R&D requires increasingly costly equipment and services and highly specialized people in several fields. This has led to mergers and alliances to share costs and risks. It has also made room for full exploitation of results.

Research consortia and networks are created globally. Industrial R&D is being globalized. R&D is placed either close to the market or close to the location of scientific expertise. This trend includes the Third World where high-quality groups in science and technology represent a big research potential in regions rich in raw materials and with vast markets. The time is over where the industrialized countries dealt with products and services with a high content of knowledge, leaving the Third World to focus on supplying raw materials and on cheap production of commodities.

No region has a monopoly on creativity. It is a challenge to integrate the Third World knowledge centres in the existing industrial R&D network in a way which ensures mutual respect and equal sharing of roles.

Integrated science, technology and innovation policy

The strong international engagement of scientists and industry and the local aim of politicians to strengthen their own individual countries may look like another paradox. However, attracting new investments for skilled and better-paid jobs is a legitimate goal for local governments. If these jobs should be based on high technology, it is essential to strengthen the framework for local business and to identify mechanisms for a more efficient innovation process, to create incentives for spin-off companies from knowledge centres at universities and larger companies.

One main element in such policies is to have a strong university system. For industry, the primary purpose of university is that it provides highly educated candidates. This is the best mechanism for transfer of knowledge. It is important that these candidates be trained to the borderline of our knowledge and that they be acquainted with the frontiers of research. This is the main reason why universities should deal with ambitious research providing new knowledge, new concepts etc. However, scientists are too often evaluated on the basis of papers published, participation in conferences and grants obtained. It means that professional scientists are attracted to safe science and cannot afford to undertake risky radical research.

Apart from providing candidates, universities can interact with society and industry. Many channels for collaboration between industry and universities on research already exist. These have helped to build up new competencies in companies.

Recently, there has been pressure on universities to participate more in the innovation process. Political pressure is being exerted to get the technology and knowledge out of the universities for the benefit of society and industry. Again, this is based on the linear model. Of course, there should be good mechanisms to create spin-off companies from universities and there is certainly a need for universities to protect their knowledge to a larger degree, as is done, for instance, in the USA through the Bayd-Dole Act. But it is important that this reaching out to ‘society and industry’ does not become the purpose of the university research. It could also destroy the present informal collaboration channels between university and industry and lead to short-termism in university research. Public money spent on universities should focus on long-term research and not mimic the political pace of being relevant.

The elements of an integrated science, technology and innovation policy may provide a strong instrument for governments to improve local competitiveness and growth. It is often difficult to formulate and implement because it involves the participation of several ministries, not only those dealing with education, science, industry and commerce, but even the ministries governing tax and finance. However, cross-ministerial efforts are difficult for most governments.

Society pull

The driving force behind industrial innovation has changed. In the past, industrial development was created primarily by ‘technology push’. Later, R&D activity was directed by ‘market pull’. Today, this has been partly replaced by ‘society pull’ or rather what may be termed ‘regulatory push’, meaning that the industrial companies to a larger extent work to fulfil the needs dictated by society.

This necessitates an intimate interaction between legislation, industry and consumers. We need more knowledge to provide a lasting basis for legislation, and implementation should be planned well enough so that the industrial effort can be redirected on a long-term basis.

Environmental policy is one example. In principle, most environmental problems can be solved if we want to pay.

We cannot afford to rely on attitudes, sentiments and, least of all, fear. We need knowledge in order to establish priorities. Industry can contribute by advising about what is possible and by participating in development of new technologies. It is evident that the countries or regions which first achieve a realistic approach and formulations of targets are also likely to gain leadership in technology.

It may, however, be a dangerous process for industry because market forces would be replaced by political processes – the latter being unpredictable. It does not help to have the best technology available if the political decisions to implement it are not taken. Political chemistry is more difficult than the chemistry involved in technology.

Too often we see that legislation is arbitrary and decisions are taken on a short-term basis. This means that short-termism will also influence the planning of industry, which might prefer then to respond to legislation rather than to be pro-active in a long-term programme for more sustainable technology. Social pull is then replaced by regulatory push. The management of this process is one of the largest challenges in the new socio-economic context.

Sociologists talk about ‘endogenous growth’ and ‘social shaping’ of technology. This means ‘shaping of social demand in the research process’ and the need for a ‘mediator’ to bring together the various players. Research and innovation are no longer ends in themselves but have to meet individual and social needs. Development should be driven by perceived needs and industrial competitiveness should not be a target, but a means of increasing the contribution of science and technology to growth.

Certainly, research and technology development should aim at growth, employment and quality of life. It is also true that technology has been the basis for advanced warfare and caused a number of industrial and technological disasters which have resulted in growing public mistrust of science and technology and its consequences.

However, there must be a limit to social control over science and technology. The relevance of research should not be assessed on an ongoing basis. The interference of the so-called ‘public player’ to create the right innovative/social network may easily lead to lack of progress.

The public and the political system may still be more effective in defining what we shall do or, rather, which of the available options we should pursue, but industry is more efficient in doing things the right way because of its ability to manage the process of bringing science to business with partners of its own choice.

More importantly, it is dangerous if science is mixed with ‘attitudes’ and politics and if public debate and the political process determine which problems should be the subject of research.

Moreover, history is full of examples of wrong judgements of the importance of new developments. These include the views of the innovators themselves (Edison was sceptical about the usefulness of the electrical bulb; IBM did not believe in the personal computer, etc.). We have also seen examples of new developments such as the P-pill leading to a non-planned change of society and our ethics.

We must maintain the scientific approach to look for truth and never stop to question the basis of our knowledge. Science should not look for consensus. It should look for true results, not agreeable results. If not, we block renewal of our societies. As for companies, explorative long-term research creates options and flexibility to manoeuvre in an uncertain, changing world.

Conclusions

Industry and governments are faced with big challenges on how best to use scientific knowledge for our long-term development. Present trends involve a number of risks. The winners will be:

- companies maintaining long-term R&D to create future options;
- companies able to integrate the research potential of the Third World on an equal basis;
- countries able to formulate and implement an integrated science, technology and innovation policy and able to avoid the traps of the linear model;
- countries/regions able to manage the ‘social shaping’ of technology, able to avoid regulatory push and to leave room for ambitious and free long-term research.

We must have the courage to explore new horizons irrespective of their relevance to present politics. In the words of Günter Grass: ‘Was richtig ist, muss nicht wahr sein. Die Wahrheit ist ein weites Feld.’ (‘What is correct need not be true. Truth is a long story.’)

Science and priorities in open societies

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Harvey Brooks of Harvard University once commented that priority-setting in science is especially difficult in times of cost-cutting. Many laboratory managers know that this is true. Since the 1980s, many countries have become engaged in public-policy exercises aimed at reducing the overall size of government and the size of deficits. The language that governments have used has varied, but has included such phrases as 'breaking through bureaucracy', 'right-sizing', 'value for money', and so on. In these processes to re-balance the public books, public science has not been spared. Thus, as government budgets declined, choices – priorities – needed to be made. The growth of science has been quite impressive across the Organisation for Economic Co-operation and Development (OECD) countries, but the share of public support for science has been steadily dropping. As a result, the private sector has become the main funder and performer of science, thus posing important questions about the role of government policies and priority-setting in intellectual property rights, standards, university research, technology transfer, and so on.

The effects of this restructuring are particularly strong in smaller and transitional economies (de la Mothe, 1999; de la Mothe and Dufour, 1990; Anerson and Lundvall, 1988).This is because they tend to have fewer researchers per capita and fewer absolute dollars to spend, while concomitantly needing to increase their exposure to world science and technology in order to stay at or near best practice. Canada, for example, produces only approximately 4% of the world's scientific and technological knowledge. Thus, its researchers need not only to carry out research but must also be good enough to recognize relevant science carried out elsewhere and import it. Thus, problems of knowledge transfer and knowledge diffusion are of paramount importance in questions of priority-setting and capacity-building.

Unfortunately, in the restructuring process, the natural (if reactionary) response is to view the situation in terms of the ideological or political bias of the ruling party. Seen in this stylized way, 'conservative' policies are thought of as tending to prefer free-market operations, minimal government intervention and trickle-down economics, whereas 'liberal' policies are thought to prefer redistributive income schemes and some form of central planning. In point of fact, there is no liberal and conservative science policy. In our globalized interdependent world economy, we are well beyond left and right. 'The Third Way' that we find in Britain and America instead displays a clear practical amalgam of interests (Giddens, 1998; Hutton, 1995; Plender, 1997) and, as we search for a new social contract between science, government and society, we find that we are operating in a new social context for science, one that is typified by a context of open societies not endless frontiers.

Science and open societies

It is important to recognize the socio-political embeddedness of science. The term 'open society' was first introduced to the English-speaking world in the 1930s by Henri Bergson (Bergson, 1932). In his formulation, the open society stood as a paradigm of development for the community of man, something that resonates at this end-of-century joint meeting of UNESCO and ICSU. To Bergson, all politics which we have known until now has been conducted on the premises of the closed society.

To a large number of English-speaking readers, however, it is the Austrian philosopher of science, Sir Karl Popper, who is most identified with the phrase. Again, like Bergson, Popper emerges from the pages of *The Open Society and its Enemies* (1945) as being a deeply humanitarian man and his conception of the open society has more deep similarities with that of Bergson than is generally recognized[1]. But in both cases, readers are invariably left to ask 'what is the open society open to?' It is of course recognized that Popper was writing at a time of great darkness in terms of the threat of totalitarian regimes[2] and centrally planned policies[3]. But this still does not lead us to a clarification.

This problem has continued to plague us today. Indeed, as Lord Dahrendorf has deftly put it: 'Some concepts have an annoying quality. They are, and potentially are attractive, but they are so loose, so baggy, that many [writers] are tempted to stuff their own preferences into them until their original definition gets confused and eventually lost. Our public discourse at this time provides illustrations, "Modernization"… "The Third Way[4]"... "New Labour". The open society has come to be a concept of this kind.' (Dahrendorf, 1998)

And yet, major figures like George Soros have chosen to anoint their philanthropic organizations with the open society moniker[5].

Nonetheless, if one can let go of the hermeneutic difficulties, we can use the concept lightly to illuminate certain characteristics of the 'open society' which are of use in outlining the contours and tensions currently associated with scientific priority-setting in small economies. It may be something of a convenience, but I find it interesting that a clutch of ideas developed around the mid-century by a loose group of Austro-Hungarians, several of whom knew each other, can be so deployed[6]. (It is also fitting that this brief connection be at least noted, given that this meeting is itself being held in Budapest.)

If we are indeed looking to flesh out the idea of an open society within the contemporary context of a knowledge-based economy or an information society[7], and therefore at the role of science and technology (S&T) *in situ*, then we must embrace an understanding of how knowledge production is best achieved.

Trial and error versus priority-setting

Thus we can say, following Dahrendorf, that 'open societies are societies which allow trial and error' (Dahrendorf, 1998). Too tight a control on the choice of research area and opportunities will be lost. Too loose a control and work will not likely be highly applicable in the domestic context. This may not sound like much of a clarification, but taken together these ideas fundamentally refocus the role of government in a world dominated by networks, partnerships, the forging of upstream and downstream linkages, etc., all dealing with science in an effort to accrue the benefits of research for domestic benefits (like health and prosperity). Within the quick tour of thoughts, the problem of priority-setting becomes evident.

Pressures and approaches in the Canadian context

Amplifying the story, one can see in more specific detail how the restructuring of world science and the rebalancing of Canadian government expenditures are affecting the federal laboratories.

The result of government action has delivered a government laboratory system that is under severe stress. This can be seen in its capacity to deliver, in its ability to set priorities across departments and focus of mandate in a rapidly shifting environment. This can be seen from an array of indicators. Since 1993, total federal government spending on S&T has fallen. In terms of research and development (R&D) this has dropped from $ 2.8 billion to roughly $ 2.5 billion, while related scientific activity has slid to $ 1.5 billion. This has been an erosion in both current and constant dollars. Moreover, the total number of highly qualified personnel has dropped from over 35 000 to nearly 28 000. This financial and human erosion has been felt more deeply in some departments than others.

On the more qualitative side, anecdotal evidence from interviews with Natural Resources Canada, Health Canada and the National Research Council[8] shows that some researchers are complaining that they are no longer conducting research, that the research is not being peer-reviewed, that they are being told to change research areas by managers because of lost person years, that they have become contract mangers, that they are being pressured by private sector interests to approve unchecked or unvalidated research results, that research careers in government are no longer competitive or viable (so that the demographic curve goes up while uptake into research jobs falls to a trickle), and so on.

Augmenting these suggestions is the fact that government laboratories continue to have a public responsibility: the public interest (however defined)[9]. Despite misplaced arguments about 'market failure', recent work has shown that government laboratories have both been adaptive to changing contexts and environments over time (and therefore there is every reason to believe that they will continue to be so in the future), and have a series of core tasks that cannot be taken over by university laboratories or industry. These include the following:

- Providing technical assistance to small and medium-sized Canadian businesses which are working in a technology-intensive area and which do not have the needed in-house expertise or equipment. This is an important role for government which has enabled thousands of firms to grow, compete and in turn create new value-added jobs. No firm or university could easily provide this service.
- Pursuing new technology development in areas such as data encryption where there is both a security issue for Canada (in privacy, for example) that will involve government regulatory functions and an economic issue (in CA*Net3, for example) where the future technology, which no one firm could afford to develop in Canada solo, can be stimulated in concert with universities and consortia (CANARIE – Canadian Advanced Network for Applications in Research, Industry and Education).
- Establishing and negotiating standards in order to harmonize Canadian and international regimes to protect Canadians and provide a favourable business climate. Again, state-to-state negotiations cannot be carried out by firms, and government science in the public interest is needed to ensure level playing fields and to avoid conflicts of interest.

- Undertaking testing and approval in areas related to drugs, biomedical devices, vaccines, blood products and the like, which clearly require government involvement as well as a research capability in order to evaluate and verify outside results for the protection of Canadians.
- Undertaking environmental monitoring for the protection of Canada's ecosystem and commons (in support of existing environmental standards and in anticipation of the identification of new environmental threats). The capacity of the government to carry out such work is critical as ecological threats emerge and as the government commits to meeting negotiated international treaty levels which would be difficult to contract out. Moreover, the capacity to conduct survey work and stock assessments in order to understand changes in the ecological systems of Canada (including the fisheries), geological transitions, and so on, are key and are germane to government – not industry – goals and mandates.
- Supporting emergency preparedness in areas such as earthquakes, floods and the like. Again, firms operating for profit would be hard pressed to undertake earthquake modelling and monitoring over the long haul and Canadians would rightly wonder if emergency preparedness, operated by the private sector, would provide the responsiveness, warning and universality that Canadians require.
- Supporting policy in the science-based departments and agencies as well as in industry, heritage, foreign affairs, international trade, defence and transportation. To farm all these responsibilities out to academic or private-sector concerns would not only create a government contract monitoring and management nightmare but could also lead to breaches of security, a decoupling of government science from government policy and a lost assurance that government and the public interest were matched.
- Continuing regulatory monitoring and compliance activities such as monitoring and regulatory control of food, drugs, consumer product safety, transportation safety and the like.
- Conducting basic research, not because government researchers should be expected to contribute to the international open literature, but because basic research will support government researchers' involvement in the latest developments, findings and techniques, and will keep vibrant an external research network which can be called upon in support of government science. Active research will serve to promote an attractive career path for researchers in which valuable scientific and technical work can be carried out, thus ensuring the revitalization of government science.

This taxonomy of mandated tasks for government science is complex and daunting to manage, but it does lend itself to a differentiation of sectors and incontrovertible government responsibilities in an 'innovation system world' and it does suggest the complexity of priority-setting, either in the macro- or the micro-managerial sense.

A scenario approach to priority-setting

In response to some of the developments noted above, the need for capacity and priority-setting work has come to the attention of senior management in Canadian federal laboratories. This has in large part been driven by the work of the ad hoc Science ADM's committee.

One concern of the analysts who carried out the study for this committee[10] revolved around the tacit view of some of the SBDAs' managers that the current context of 'lost resources' simply means (a) that a principal task is to retrieve these resources from the public purse, and (b) to put them back into those same activities which were cut. Instead it was the view of the analysts that following such a route would reinforce the long-standing territoriality that exists between departments and that has in part been responsible for the current situation. Rather, SBDAs should (c) take the opportunity to seriously evaluate and reorient themselves, strategically plan and position themselves vis-à-vis their core mandates, core clients and the central agencies, and proactively retool themselves managerially. In the analysts' view, 'retooling' and 'reorienting' might well involve horizontal planning and management across the SBDAs (i.e. the creation of a science portfolio within government), striking alliances, and building networks and linkages both across government and between government-business-university[11].

In order to assist managers move in this direction, 'capacity' in this study was broken down into a series of 'drivers':

- scenario description drivers;
- outcome drivers;
- implications for capacity-planning.

In the absence of any Canadian Foresight study of the breadth and scope found in Australia and Britain, this analysis was not intended to replace science capacity planning at the operational level. Instead, it was meant to help managers and policy staff test the robustness of their own capacity plans within a broader planning framework. To achieve this, the study postulated four different scenarios.

- What if the future context of the SBDA is largely as it is today?
- What if there is a gradual decline in the resources available for S&T performance across government?

- What if there is an increase in S&T resources?
- What if the future unfolds in a way that is very different from the one for which we are planning?

Although each scenario was grounded in contemporary policy environment – in particular the federal government's S&T strategy[12] and its government-wide planning exercise[13] – the scenarios were meant to be somewhat provocative in order for managers to test their current thinking.

In Phase 1 of the study dealing with the scenario description drivers, environmental, economic, industrial, social, fiscal, policy and S&T elements were reviewed. In Phase 2, research, policy advice and staffing considerations were reviewed, along with infrastructure and partnerships. Lastly, implications were sketched for SBDA roles, resources, personnel, facilities and equipment, science-policy linkages and business arrangements. As a result, a number of themes thought to be worthy of consideration were revealed:

- linkages, networks and alliances are key;
- money is not the solution;
- skills planning needs to be future oriented;
- technologies are moving too fast;
- cross-department cooperation is increasing;
- research or science assessment?

Conclusion

Support for science policy often involves providing timely information to government decision-makers about what to do on a particular issue. Given that information is often incomplete and results uncertain, scientists are often reticent to offer advice in this regard. This points to a gap in capacity that needs to be narrowed by government scientists understanding their role qua government scientists, not just 'scientists', and thus reveals another level of tension regarding the government-science relationship in open societies. In an age of surplus budgets, which Canada is now entering, priority-setting will only become even more difficult than Harvey Brooks suggested.

Notes

1. There are of course numerous important differences, and Popper does trace the origins of the open society to the ancient Greeks.
2. Popper called this book 'his war effort'.
3. For an excellent review of the debate over central planning, see Daniel Ritschel, *The Politics of Planning: The Debate on Economic Planning in Britain in the 1930s*. Oxford Historical Monographs, Oxford University Press (The Clarendon Press), 1997.
4. One could add 'the civil society'. See John Keane, *Civil Society: Old Images, New Visions*. Polity, Oxford, 1999.
5. Soros' organization is called The Open Society Institute. There also exist the Öffene Gesellschaften and the Societá Aperta. I am grateful to Lord Dahrendorf for bringing these latter organizations to my attention. Personal communication, 20 January 1999.
6. This should hardly be surprising given the widely recognized talents in the arts and sciences displayed by those from Vienna and Budapest and born between 1890 and 1920. See Laura Fermi, *Illustrious Immigrants: the Intellectual Migration from Europe, 1930-41*. University of Chicago Press, Chicago, 1968.
7. I myself dislike these terms and, if anything, prefer something like 'the innovative society' given that information is not knowledge or wisdom (so the social glue of society – such as trust and other forms of social capital – is lost) and every economy is knowledge-based and always has been, as Karl Polanyi has pointed out in his *Great Transformation*.
8. Conducted by John de la Mothe and Ron Freedman as part of 'SBDA capacity studies' in late 1998 and 1999.
9. John de la Mothe, 'Government Science in the Public Interest'.
10. John de la Mothe and Ron Freedman.
11. For a detailed discussion of the development of the federal laboratory system in Canada, see Paul Dufour and John de la Mothe (eds.) *Science and Technology in Canada*. Longman, London, 1993. For a sketch of how this new governance structure might look, see John de la Mothe and Gilles Paquet, Circumstantial evidence: a note on science policy in Canada, *Science and Public Policy*, 21, 4 August 1994: 261-268.
12. *Science and Technology for the New Century.*
13. Canada 2005.

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S&T priorities and policy issues: the Latin American experience

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Of the questions proposed by the conveners of the present thematic meeting, I pick up two for comment from a Latin American perspective: how can science respond to the different needs of the region? and, how does one influence science funding and human resource development? There is quite a lot of detail available on how science has grown in the region, as there is a growing body of empirical knowledge produced by sociologists and historians of science and economists of innovation. The answer to the two questions of the present meeting, however, requires a synthetic understanding of the many ingredients of development, which has not been forthcoming in view of the great uncertainties and failures surrounding development efforts. More modestly, I will simply try to put together some of the social trends that accompanied the institutionalization of science in Latin America, while in the world it was growing into a major productive force. I propose two main theses that will structure my presentation.

- The limited and frustrating development of science and technology (S&T) capabilities in Latin America and the Caribbean after the Second World War was part of a broad process of economic and political change set in motion for dealing with a very unequal socio-economic set-up and has to be viewed in this context. Research grew largely in teaching institutions and often distant from industry, which did not place significant demands on the local scientific establishments. Thus the region came to have some very good scientists and engineers but the national research systems have not yet reached a critical size and the national innovation systems lack density.
- The new conditions of globalization (as well as the specific domestic context after 50 years of ‘development’ facing the countries of the region) mean that we are entering a largely new territory which is not yet mapped but whose culture, rhetoric to the contrary, seems to be characterized by exclusion and concentration. Although there is still more talk than action about North-South collaboration, research appears today as a basic ingredient of economic success everywhere. Private capital, with its rules and time constraints, has replaced development aid as the main source of external finance for developing countries, while lobbies for science in Latin America are still weak. No ready-made recipes are available, though. Institutional, social, cultural and political factors count as much or more than economic and scientific ones. The needed changes are, of course, partly economic and scientific, but scientific activities cannot by themselves achieve anything unless there is a long-term commitment to development.

I present next what I consider to be four of the most pressing needs conditioning S&T policy and development in Latin America: politics, democracy and learning processes; education, poverty and culture; the regional demography of S&T; and relevant science for specific needs and conditions. I will then briefly discuss the new patterns of knowledge flows and the complexity of requirements for resource mobilization in today’s world.

Politics, democracy and learning processes

Politics must overcome several obstacles in Latin America. A major difficulty is that it is held hostage to multiple restrictions imposed by a power system designed to mediate between the diverse and contradictory interests of societies that must manage at the same time the macro-economic order, financial scarcity and social inequity. One cannot overlook that still one out of every four Latin Americans lives on less than US$ 1 a day and inequity in income distribution is more accentuated in our region than in all others.

Another hindrance is that politics in the region is still worried about keeping alive the old public structures. But the ‘provider’ state is in crisis and its underdeveloped version, which is the one known in Latin America, has no chance of responding to the avalanche of social demands. Disorganization and administrative disorder affect the state’s performance as much as fiscal restrictions. Associated with this is the short-term syndrome: immediate electoral dividends are the rule in the political game. Even when there is a sincere democratic concern on their part, politicians are fully absorbed trying to solve their constituencies’ immediate problems and it is not easy for them to pay attention to the longer term, essential to industrial and S&T strategies and to the constitution of an educated broad social base.

The influence of the mass media, particularly TV, is immense. Ironically, public deliberation about fundamental options is practically impossible. Instead of open democratic communication, what is obtained is tough competition for the control of the topics that may reach the public agenda. The relative poverty of political information contributes to further deterioration of the democratic climate, fostering cynicism, withdrawal and rejection among the public, while only a few groups intervene in public deliberation and decision-making. The middle-class consumer has grown enormously; however, it is a consumer who feels threatened by current difficulties and does not assume the citizen's voice.

Democracy supposes that political sectors use the available information and knowledge more intensely, and are capable of unleashing experimentation and learning processes in a variety of domains, from the school system to the export sector, from government institutions to universities, from hospitals to communication industries. The truth is that we are still far from building democratic societies.

Education, poverty and culture

Education is a major bottleneck in the prospects of most countries. Although the region has invested heavily in education, marked differences are observable between countries and also in their performances. Results in the educational field are linked to the evolution of the poverty phenomenon in the region. The structural reasons for the increase in poverty, which is becoming increasingly acute, are believed to be found in the employment market: fall of salary levels, income distribution, growing precariousness of employment and, lastly, unemployment. The economy in Latin America is of an exclusionary type. Due to the insufficiency of the industrialization drive, high unemployment and underemployment, even among the educated, was regarded in most countries as a serious social issue in the 1960s and again in the 1990s. Poverty increases at a firm pace on a continent where most countries live in retrogression or recession; in 1996, eight out of 100 Latin Americans ready to work did not find a job in a trend that is clearly shown to be long term and not a transitory spell. Governments' development strategies have in general been indifferent or opposed to a more equitable structure of income distribution and have concomitantly retarded the development of educational institutions.

In the 1990s, most governments have started major educational reforms. Their implementation and effects remain to be seen in the different countries. Given the growing importance of innovation capabilities in sustaining international competitiveness, efforts are being made to strengthen university-industry and research institutions-industry collaborations as well as the training of technicians and administrators. Although universities are rapidly expanding their research and development (R&D) activities in basic and applied research, their sub-critical size may prevent a more effective response to the dynamically changing technology environment at the international level.

Cultural factors must be taken into account in connection with learning capabilities. Among the new common features of social conduct that are often pointed out are those of governance: attachment and loyalty to the work site, and recognition of the legitimacy of authority in civil society or in connection with government rules. There is also a lack of trust, i.e. the expectation arising within a society of regular, honest and cooperative behaviour. When dishonesty and corruption take over the state apparatus, society finds it difficult to innovate organizationally, since the existing low degree of trust inhibits the emergence of a wide variety of spontaneous social relationships. Widespread distrust in Latin American societies imposes a heavy burden on all forms of activity. It also reaches the S&T domain, because lack of trust leads to poor linkages between S&T actors resulting in low R&D productivity, reinforced in turn by a lack of social capital.

Demography of S&T

There are too few scientists and engineers in Latin America and the Caribbean. Due to a series of factors, there is insufficient local development of undergraduate and graduate education in S&T and an important number of university students who complete their studies in the developed countries do not return home, joining the many highly qualified professionals from Latin America who also emigrate. The reasons determining this continual flow of professionals from the region towards developed countries are structural. With an estimated minimum cost of tertiary education in the region of US$ 25 000, the professional migrations of the last 35 years have cost Latin American countries US$ 30 000 million. Since the region invests an annual amount of US$ 3 000 million in S&T activities, the loss resulting from the expatriation of its professionals represents 10 years of regional investment, and nine times the total Interamerican Development Bank direct contribution to S&T in the region since 1961.

Paradoxically, all through the 1990s a renewed narrowly elitist approach to the selection of those scientists who will be supported has been adopted that, contrary to avowed expectations, ends up discarding people with 'unacceptable' profiles. But the development of Latin American societies requires that there are more, not fewer, people adequately educated and trained. It is as if, consistent with the trends in the wider society where exclusion has become the most painful and heavy burden of a period of 'impressive economic growth', science is also becoming a domain for the extension of the criteria of social exclusion and power concentration.

Doing relevant research for specific needs and conditions

The relevance of research is closely related to its social and economic impact. Sometimes blanket statements are made about scientific research in Latin America being irrelevant and a luxury. Since superfluous things ought to be eliminated in times of crisis, unless research demonstrates its relevance – some would argue – it should be reduced to its minimum expression. The option, however, is not between good science for its own sake (going back to the 19th century *esprit*) and science for development. And science, basic or applied, should not be oversold as providing ready-made solutions to problems which have very different causes. Things are not so simple, and the understanding of the problems of development has repeatedly proved to be very elusive.

However, when, as in Latin America, nations have only small S&T communities, resulting externalities become very important because those communities enable access to the international pool of available knowledge, expertise and skills through their capacity for interaction and visibility; they can read and interpret results, eventually discovering novel solutions or providing short cuts for solving technical problems that seem insoluble, and are able to guide strategic decision-making in technical matters concerning their societies. Sheer observation shows that many of those ‘few’ who carry out S&T in the region often multiply themselves doing ‘relevant’ things in the best sense of the word.

Priorities and policy issues in the new international scenario

In the foreseeable future, growth will rely on collective knowledge and creativity. Thus, to benefit from current globalization and minimize its risks, Latin America needs rapidly to multiply and strengthen its learning and scientific capacities as well as its institutions and social networks. Above all, the particular countries have to elaborate a strategic view of their integration into the new world setting, which will hopefully be creative and not a mere copy of the models from the developed countries, which have more often than not led to failure when duplicated.

Societal democratization implies, among other things, the achievement of social equity, which implies high and sustained economic growth. But clearly, growth will not be sufficient. When the cake was bigger in the good old post-war days, it was not equitably sliced; and closer to the present, some have been eating portions before others have received theirs, with a consequent increase in concentration. Distribution is not necessarily tied to national wealth. A country may be very poor but have a less contrasting income distribution than a wealthy one. The universalization of norms and rules and the exercise of a more equitable distribution of social benefits in our shrinking world implies that when countries and cultures get in contact, criteria to assess competitiveness, institutions and performance tend to become universalized. This is reflected in aspects as varied as country-risk classifications, the definition of quality systems and standards, the measurement and comparison of school results and the pressure to establish international accreditation systems for easing the mobility of scientists, engineers and other professionals.

In the Latin American experience, resource-rich economies have had difficulties making the jump from resource exploitation to skill- and capital-intensive manufacturing. In several countries, large modern businesses coexist with an insufficient number of dynamic and innovative small and medium-sized enterprises (SMEs), which are necessary to face the challenges of industrialization. More research-intensive higher education systems and R&D organizations able to incubate technical entrepreneurs and creative financial service markets, on the one hand, and the extension of networks of technical support systems in the industrial areas would help to enhance the performance of the SMEs.

In those countries where there are S&T establishments in existence, firms should seek different means of gaining access to foreign technologies by exploiting a varied range of mechanisms from strategic alliances to mergers and the acquisition of foreign firms with the help of the existing local R&D capabilities. Scientists, engineers and technicians as a collective have a valid potential that can be used in the production and adaptation of S&T knowledge. Their major liability lies in the fact that their political position in their countries is marginal to decision-making (neither politicians nor firms have understood and had a real interest in science, much less in local science). Thus researchers have to rely only on their individual and collective quality to show that they are worthy partners in international scientific collaboration. Things, however, should go beyond this to make governments and other stakeholders aware of what is to be gained by defending and promoting their own domestic S&T establishments.

Major reforms must be intensified in higher education: new curricula in science, technology, the humanities and the social sciences are needed, and there has to be a renewal, improvement and motivation of well-trained teaching and research staff. All this requires major investments. But money is not the only problem. In addition, institutional inertia and vested interests have to be attacked and defeated, and seriously conceived alternative educational programmes should be put in place to enable the needed transformation of society and culture through education and science. A major drawback is the lack of understanding among government officials and other decision-makers, who often treat higher education institutions (HEIs) in the same way as other large bureaucracies. Many HEIs are powerless to orchestrate the needed changes, keeping a strategic distance from the immediate pressures of the market and the partisan concerns of the government in power in order to serve the public interest.

The deep inequalities and asymmetries in Latin American societies constitute a serious handicap for any international collaborative architecture that may be conceived to prevent the result from being once more unbalanced and distorted. The current gap in scientific knowledge and technological know-how between the developed countries and the Latin American ones can only be narrowed and eventually overcome through concerted action between domestic and international efforts. It has been common among the richer countries to think basically in terms of transfer of embodied S&T irrespective of its usefulness, adequacy and need in the adoption context. It is simply not true that the most advanced technologies are geared to the needs of most developing countries. International collaboration in research, particularly that funded with development aid money, has tended to be focused on short-term technical fixes rather than helping developing countries to increase their self-sufficiency by building up local research capacity.

At present, richer countries are shifting their position vis-à-vis international projects aimed at improving scientific capabilities in developing countries. Now, many politicians in the developing countries accept that research is a necessity if developing countries are to be helped to solve their problems. Old calls from Latin American scientific lobbies for ‘coordination of research effort’, ‘building research capacity in the South’, and ‘equal partnerships’ seem to be making an inroad into the European and American offices where development aid policies are elaborated. But for problems to be rightly grasped on both sides, there is still a need to negotiate the terms of collaboration. How Latin American and other developing countries respond to this new approach will be crucial in enabling an effective transformation. That is why it is so important to debate the ‘whats’ and ‘hows’ now. Lobbies for science or for topics which include scientific ingredients in their definition are weak in Latin American countries, whose politicians are seldom knowledgeable of technical matters. It is obviously necessary, then, to induce a greater participation of scientists in matters related to public policy to help produce an equivalent understanding on both sides.

S&T in the Kingdom of Saudi Arabia: priorities and impediments

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Shedding light on Saudi Arabia

The Kingdom of Saudi Arabia covers an area estimated at 2.25 million km^2. It has a population of nearly 17 million. The average yearly population growth rate is equal to 3.8%. The Kingdom has been conscious since unification in 1932 of the importance of scientific research and education in providing necessary manpower. Discovery of oil and gas as main natural resources in 1938 helped the Kingdom speed the wheel of scientific and technological development. From the beginning, the steady orientation of the Saudi leadership was towards investment in the educational and manpower sectors. The Kingdom believes in one faith, Islam, and since science and scientific methods were the creations of the Islamic civilization, the Kingdom made noticeable strides in finding most advanced technological solutions to their own problems in areas such as agriculture, industry, communications and housing.

This resulted in the education sector achieving higher growth, as shown hereunder:

- the number of students in general education increased to more than 4 million;
- the number of schools, institutes, colleges amounts to more than 22 000;
- the number of teachers has reached about 260 000;

- the number of students in the universities is more than 260 000;
- the number of students accepted in the universities is 80 000;
- the number of graduates is around 37 000;
- the number of faculty members is around 9 500;
- the number of S&T colleges in universities is 29 out of a total of 67;
- the number of citizens holding a higher diploma or Master's degree is around 25 000;
- the number of citizens holding a doctorate degree is about 10 000.

Establishment of S&T organization

The area of science and technology (S&T) was specifically emphasized by the Kingdom's development plans through the establishment of scientific research institutes and centres. The aim was to catch up with nations which are developed scientifically and technologically. Thus, King Abdulaziz City for Science and Technology (KACST) was established on 18–12–1397H (October 1977) as an independent scientific organization administratively reporting to the prime minister, with headquarters located in Riyadh and with the possibility of branches in other cities of the Kingdom. It has a Supreme Committee to control and handle its affairs. The main objectives are to support and promote scientific research of an applied nature, coordinate the activities of the scientific research institutions and centres in line with national development requirements, and cooperate with the competent bodies to define the national priorities and policies in the field of S&T for building a strong base in the agricultural, industrial and mining fields.

Priorities of S&T

The methodology for selecting and determining S&T priorities in the Kingdom has passed through three consecutive stages since the start of National Development Plans in 1970. It started with decentralization through directives, followed by coordination and integration and ended with the present stage of comprehensive planning for S&T.

The Kingdom has worked for the last more than two decades on setting up unique and ambitious plans and priorities for comprehensive economic, social and human development. The main features are: proposing a national policy for S&T, and drawing up a planned strategy for its implementation; supporting, encouraging and conducting applied research programmes; assisting the private sector to conduct research on agricultural and industrial products; supporting joint research with international scientific organizations to keep abreast of the latest scientific developments; and offering scholarships to develop manpower skills and to enhance research capabilities and expertise.

All these years, KACST has played a prominent role in the Kingdom's scientific and technological achievements in diversified areas by setting up a number of important projects for research in the fields of engineering, medicine, agriculture, nutrition, petroleum and petrochemicals, pollution and environmental protection and basic sciences. It has also completed the infrastructural construction of the basic facilities needed to support scientific research in the Kingdom, including management of research grants, setting up of communication networks and S&T databases.

Accomplishments

KACST has succeeded in establishing fully-fledged research institutes which are playing a vital role in supporting and promoting scientific research; these are presently carrying out research in the following areas.

- The energy research institute is responsible for solar energy and new/renewable energy research. Its goal is to adapt and develop new energy technologies that are appropriate for the social and environmental make-up of the Kingdom, especially supporting economic, industrial and agricultural development in various regions and proposing rational use of energy resources. It is also working on solar radiation and wind energy measurement networks.
- The astronomy and geophysics research institute aims to conduct applied research in these fields, carrying out studies on monitoring earthquakes and mitigating their effects. It is also working on establishing Saudi laser ranging and lunar observatories, and seismic monitoring national networks.
- The space research institute supervises a remote-sensing centre in Riyadh and adapts and utilizes remote-sensing technology for development purposes, collection and distribution of satellite data, recording satellite images, search and rescue programmes using satellites, photo-processing and analysis.
- The atomic energy research institute adapts nuclear sciences and technologies and utilizes them in support of economic, industrial and agricultural plans, conducting nuclear and atomic energy research including research on nuclear reactors and safety and advanced radiation processing for the protection of the environment.

- The natural resources and environment research institute conducts research and studies on various environmental problems to develop and conserve natural resources and to enhance the level of contribution on global environmental issues in the areas of arid and semi-arid lands, earth sciences, water technologies, environmental pollution control, biotechnology and genetic engineering, fish culture and gene banks.
- The petroleum and petrochemical research institute adapts and utilizes petroleum and petrochemical technologies in identifying technical problems, conducting research on environmental protection from wastes, improving oil reservoirs and developing industrial processes and membrane technology.
- The electronics and computers research institute conducts research in the fields of S&T of electrical engineering, bioelectrical engineering, systems engineering, computer engineering and computer sciences to design and develops systems, hardware and software.
- The measurement and instrumentation centre designs, manufactures and maintains equipment and instrumentation needed for research by all the research institutes of KACST, developing standards and calibration performances and acquiring and operating technology for major or multiple users of equipment.

All the above institutes are working in diversified areas of research and investigation. KACST's scientific activities are contributing immensely to implementation of useful technical programmes for the betterment and progress of the people and ensuring technological advancement and future aspirations.

KACST has also succeeded in establishing highly sophisticated information and national networks containing foreign databases, information systems and computer networks, and provides Internet services in the Kingdom. Through the Directorate of Patents, KACST has set up rules for registration, inspection and issuing of invention and copyright licences and follows intellectual property issues at international level as per directives of the World Intellectual Property Organization (WIPO) and World Trade Organization (WTO) regarding implementation of patent laws.

Appreciating the importance of the human factor in any development process, KACST played a distinguished role in preparing Saudi *cadres*, so that government and private institutions can utilize them to increase productivity and upgrade the level of their performance in various activities and work. It also formed national working teams to set scientific and technological priorities for different development sectors.

The Kingdom of Saudi Arabia is presently discussing its entry into WTO to influence the transformation of secluded economies into a unified open economy and open market economy, as this will make it difficult for any country to achieve desired development outside the range of WTO. Orientation towards this market and forming the competitive attributes for national industry and advancement of product quality becomes the main mover for exporting – which is one of the characteristics of S&T priorities.

Presently, KACST, in cooperation with the Ministry of Planning and other national bodies, is in the final stages of preparing a comprehensive long-term national plan for the Kingdom (2000-2020 AD). The plan aims to design a national long-term policy and strategy for S&T and is considered to be a major transformation point for the Kingdom to confront major scientific and technological changes at the local, regional and international levels. KACST has called upon all those in the relevant government and private sectors, universities and research centres to participate in preparing the different stages of this long-term plan by studying and evaluating the human, financial and institutional factors of present S&T research and to perform 18 scientific studies in different fields which are identified as possible priorities.

Impediments facing S&T priorities

In previous parts of this paper, there was an illustration of the reality of S&T priorities and future challenges that influence their selection and determination. This was done by observing in a general manner some of the changes and orientations at the global and regional levels and these observations formed a base for identifying some of the impediments that face S&T priorities. The most important are the following.

- *Shortage of information and data:* the non-availability of required quantitative and qualitative information and data is considered the most important impediment in the selection and determination of S&T priorities. This is attributed to the modernity of data, shortage of executed studies and weak coordination among related institutes, which prevents planners and decision-makers from getting information easily and on time.
- *Great deficiency in specialized experience:* institutes not having enough national experienced cadres in the fields of S&T, a fact overlooked by the academic institutions. This makes seeking aid in the form of foreign experience insufficient to increasing demands.
- *Private sector:* the private sector is most important and represents the main part of the national economy, but due

to weak care for S&T development, this sector has not been able to develop ability in advanced technologies and a competitive environment; thus, the capacity to select, determine and execute their priorities was weakened.

- *Scientific and technological development and national policy:* developed and developing countries agree on a stable reality connected to the nature, standards and controls, opportunities and investment in the fields of S&T, and the most important absence of conscious national policies and strategies. This is one of the major impediments that influence the selection and determination of S&T priorities in the region.

Thematic meeting report

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Background contributions

The meeting was based on five contributions providing a background for the discussion: a presentation of science developments in a long-term perspective, an industrialist's view on current trends and three 'case studies' by policy-makers or analysts outlining priority issues in countries in North America, Latin America and the Arab world. The main messages from their presentations – developed in more detail in their papers – are summarized below.

In his long-term perspective, T. Gaudin (France) underlined the increasing importance of life sciences and cognitive sciences underpinning the post-industrial era and suggested accordingly a new organization of scientific disciplines. Observing that in the industrial era the 'society' was somewhat 'instrumentalized' through technological developments, he insisted on the need to reverse this process by various means, including the application of ethical principles. While there had been a decline in national security as a major driving force for advanced research, he noted that the latter was being replaced by an intense world economic competition, in which the main actors were the (large) enterprises. In such a context intellectual property issues became crucial.

Industry's attitude towards science was outlined by J. Rostrup-Nielsen (Denmark), who pointed out the need for governments to support long-term research as a main source of flexibility and future options, at a time when the research and development (R&D) efforts of the private sector, and notably the large enterprises, tended be more and more oriented towards the short term. He warned against an excessive 'regulatory push' from governments. He insisted on the fact that the best mechanisms for knowledge transfer were highly educated people. Finally he suggested that successful businesses would be those which integrated the research potential of the Third World which, in his experience, was significant in a number of countries (e.g. India).

Policy trends and issues as experienced in a number of advanced countries were illustrated by J. de La Mothe (Canada). He pinpointed, in the case of his own country, the sharp decline in government support to the overall R&D effort and the dramatic consequences this had had, in particular, for government laboratories' activities, as basic infrastructure of the national innovation system. He outlined also the planning and foresight process that had been put in place at the federal level for prioritizing R&D support, taking into account both the orientations of the business sector and the objectives of the provincial governments, which played an important role, too.

The Latin American situation was depicted by H. Vessuri (Venezuela), who noted that so far the globalization process had been accompanied by an exclusion process within the concerned economies. She observed that the brain drain process affecting the science and technology (S&T) workforce was very costly to countries, surpassing considerably their S&T expenditures as well as related foreign assistance and cooperation. She considered that a better integration of S&T in the overall development process would require a stronger relation to the local context, more efficient organizations for S&T and more generally a societal democratization.

Illustrative of the Arab world, the case of Saudi Arabia was outlined by S. Al-Athel, who described the different phases of the policy-making and priority-setting process since the 1970s. After an initial phase characterized by strong decentralization, a more coordinated and centralized approach was under way. The Kingdom of Saudi Arabia, like its neighbouring countries, was having to face some basic challenges: an economy still strongly dependent on oil and gas, a rapidly growing population, a relatively weak private sector and a chronic difficulty articulating national policies and strategies. At the same time, a very significant investment had been made in education at all levels.

Thus, the importance of local conditions in their inherent diversity, and with their specific difficulties, was clearly emphasized, as was the need for due consideration to be given to key general features of the 'new socio-economic context'. Chief among those features were the increasing role played by 'global' industry in the funding and exploitation of R&D and the concurrent need for local populations to have better control of, and to benefit more from, scientific and technological enterprise.

Principles for priority-setting

Against this background a set of general principles emerged from the discussions for guiding the priority-setting process.

- No country can escape from making priorities and being selective, while the scientific enterprise appears to be more and more costly (as shown for instance by the rising unitary costs of scientific articles published in 'mainstream' journals).
- While the objectives for technological and economic competitiveness remain important, concerns for the security of nature and social and human development should receive increasing attention and priority.
- In a number of instances, choices will have to be made between investing in advanced 'frontier' research and investing in research oriented towards the application of existing knowledge to improve more directly the quality of life and the environment, with great attention being given to local needs and competencies as well as to necessary specializations.
- Government authorities have to provide long-term research with enough support, while there are increasing signs of 'short-termism' in business approaches. The place for such long-term research is primarily universities and public laboratories serving collective needs.
- Government support to small (high-tech) firms, as sources as well as users of exploratory research, should also be secured; more than ever, these firms play a unique role in the innovative process and notably in pioneering fields (e.g. biotechnologies).
- Great attention should be given to patenting and intellectual property issues in general, as they are conditioning the use of research and technology and thus could strongly influence priority choices; of particular importance are property issues of living organisms and of software (some of which are becoming world standard and would normally be considered as 'common goods').
- Priority-setting should give due consideration to increasing opportunities for South-South cooperation, which can lead to considerable exchanges of experience and knowledge at a reduced cost.

It is crucial to invest in high-quality S&T education. However, that should be done with due consideration for local needs and capacities (following the example of several small advanced countries, students can systematically be sent abroad for PhDs, thus contributing efficiently to networking with international science and business). Science should be made more accessible to the public by the establishment of appropriate mechanisms for dialogue as well as through the provision of user-friendly technologies.

Finally, it was emphasized that the priority-setting process should be placed within the broader framework of S&T and innovation policy – cutting across a number of government responsibilities and related departments. This policy itself cannot be disconnected from larger reform plans, notably in developing countries. In this connection structural adjustment programmes should not undermine S&T capabilities, which are the basis of long-term growth. Making efficient use of available well-educated resources in developing countries should receive the highest attention.

These principles may appear too limited in substance and number. However, strictly applied, they would gradually induce a significant change in the way science and research are being integrated into the overall development process and put at the service of human needs.

Gender and science, engineering and technology

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The summary is meant to provide a highlight of the framework for the discussion in the present thematic meeting, which discusses science as a subject covering science, engineering and technology, or SET. Discussions on the gender issue of science are designed to address the continuing prevalence of inequality between women and men in SET utilization, development and control, as well as the differential impact of SET development and utilization on women and men. A gender perspective is an essential component of the strategy for 'sustainable progress of SET in society and SET for society'.

Equality in access to the benefits from SET must be considered with a cyclic approach or from conception to old age. Access to SET ranges from access to information, knowledge and to the use of SET for one's growth, development and welfare, access to a quality environment, both natural and social, access to education and training in SET as a precondition to enable one to utilize, develop and manage/control SET's use and development direction, access to opportunity to develop a career in SET and, finally, access to SET decision-making processes and structures.

Equality in contribution to, or as agents of, SET development and their utilization for the benefit of society involves equality in SET careers, which includes the recruitment process, remuneration, on-the-job training, membership of scientific societies and acquisition of research and development (R&D) funds, equality in decision-making processes and structures for research priority-setting, technology choices, local knowledge and indigenous technology contribution to human survival, sustainable development, peace and security, and their development, SET training and career development, management and funding.

Equality in SET planning, programming, monitoring and evaluation of progress involves the following: analysis of SET policies and programmes and their impact on society, including their differential impact on women and men, the extent to which the practical and strategic gender needs of women and men are being addressed and met, advocacy for development of SET for society and the building of society for the advancement of SET.

The gender differential impact of SET should be addressed through a comprehensive approach emphasizing the ethical issues associated with both the conduct of scientific research and the application of its findings; the assessment of the extent to which SET aimed at benefiting disadvantaged people is really benefiting both men and women equally or the extent to which SET that is specifically aimed at empowering women does indeed benefit women rather than simply meeting their practical and immediate needs and in the long run perpetuating a disadvantaging stereotyped role of women; the introduction of new, more efficient and effective technology which sometimes displaces women from their source of income or opportunity for promotion and most of the time only meets women's practical needs and neglects their strategic gender needs; technology choices and design, which often fail to take into account women's real needs and concerns, due to the excessive priority given to efficiency of time and non-human energy.

Three of the main causes of inequality in SET are:

- the use of the biological nature and the different but complementary human reproductive functions of men and women by society to build and attribute stereotyped gender identity as well as a social role for women and men; as a result, gender identity varies from society to society, from culture to culture, from religion to religion and from time to time;
- gender identity has been built and perpetuated, to a large extent, by a 'miss interpretation' of religious teachings or by underlying cultural values and traditional practices on the one hand and the neglect of the existing legal framework of the society or country concerned, on the other;
- the inability of all concerned (governments, SET, society) – as well as the lack of complementary and consolidated efforts between the social/humanitarian scientists and the so-called 'hard scientists', between religious and traditional leaders, between political and economic leaders, between law-makers and law-enforcers, and among groups within the civil society – to recognize both the benefits and disadvantages of gender equality and inequality for society and for SET society itself, which in turn has resulted in the lack of political commitment and legal framework for the achievement of gender equality and equity in SET.

The achievement of gender equality and equity in SET requires a set of indicators to monitor progress and assess results. Such a set of indicators may include the following:

- the absence of a gender-discriminatory content from the legal framework, policies and strategies for the advancement of SET and their application to development;
- the absence of gender discriminatory organizational or corporate culture from SET establishments, governmental and academic institutions, research councils and even research teams;
- equal participation in SET education, careers and decision-making;
- equality in benefiting from SET;
- elimination of disadvantages caused by SET development and application;
- regular publication of gender-disaggregated SET statistics;
- increased studies of the gender-differential impact of SET and their use in the formulation of SET policies, strategies and programmes.

Obviously, the gender issue in SET requires more thought and action by all concerned. First, it is necessary to identify a set of strategies to deal with the key areas such as:

- how to achieve gender equality in access to the benefit of SET for everyone's survival, for sustainable development, for peace and security;
- how to achieve equality in access to opportunity to contribute to the development and use of SET for society and to the creation of society conducive to SET progress and support for sustainable development;
- how to eliminate or remove structural constraints to equality and equity in SET such as a gender-discriminatory legal framework, organizational/institutional culture, gender-blind SET progress indicators as well as monitoring and evaluation system.

Second, it is extremely important to involve and mobilize strategic actors: governments, legislators, scientific societies from national and international levels, especially those members of ICSU, intergovernmental and non-governmental organizations, in particular UNESCO, SET funding institutions, the civil society – social, traditional and religious organizations and leaders – and the media, as well as parents and teachers.

Research and informal education by women scientists for sustainable development in Africa: a role for TWOWS

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'*It is science alone that can solve the problems of hunger and poverty, of insanitation and illiteracy, of superstition and deadening custom and tradition… of vast resources running to waste, of a rich country inhabited by starving people who indeed could afford to ignore science, and those today. At every turn we have to seek its aid…. The future belongs to those who make friends with science*.'

PANDIT J. NEHRU, LATE PRIME MINISTER OF INDIA

The above statement is even more relevant today for developing countries because their governments need to use science and scientific methods to improve the quality of life of their peoples.

Scientific inquiry and innovation are part of the human mind. Scientists in any country work at this process of inquiry about humans, the world and the universe. Such inquiry and its methods make up science.

The place of research or scientific inquiry is fundamental and significant in the life of any nation. Research on any subject is the process whereby a people seeks information, analyses that information, reaches conclusions and uses such conclusions to act and/or make appropriate and informed decisions. Such informed decisions, which benefit mankind generally, should introduce more intelligent and relevant information that further improves and expands knowledge and its applications in all spheres of human endeavour. Thus, research is the backbone of a nation's development and it is an indispensable tool for transformation, change and development. Results achieved lead to more innovations and inquiry. Science by its various inventions, innovations and applications to industry, to government and to management improve the quality of life. When results of research are managed and put to good use, they generally lead to improvement in the quality of life for all. Otherwise, it could cause unprecedented damage to humanity and the environment.

This paper is concerned with how an organization of women scientists in a Third World country can be relevant and useful to science and research in order to improve the welfare of citizens of that country. Many developing countries have a myriad of problems. At independence in the 1960s education for all citizens was considered the solution for development. Today, with the experience in education, especially higher education and research, there is serious reflection on the need for a better linkage between research in the universities and industry and business: thus, the concern about with how women, especially women scientists, can play a major role in the process of changing the status of an underdeveloped or developing country like Nigeria to that of a developed nation.

Research in S&T, a critical factor

In examining the economic and technological strides which certain nations have made in the last half of the 20th century, research in science and technology are usually accepted as critical factors that assisted these nations in making the leap from poor, underdeveloped agricultural countries to developed industrialized countries. Success here is measured in terms of a country being able to provide free education for its youth, good clean water, health programmes that are regular, available and affordable. Also a large percentage of the population of such countries (90%) are literate and skilled persons, who live above the poverty level and enjoy such basic infrastructures as good housing, good roads, transportation, communication, potable water and electricity. Other critical factors necessary for growth and development must include good and stable governance, law and order, and value systems that stand for openness, cooperation and competition but are anti-corruption. In this presentation, the concern is to underscore the importance of research in science and technology for sustainable development as essential and necessary, though not sufficient, factors for transformation, growth and an improved standard of living of the people.

To research any situation, one must be aware of the problems, determine the issues and work towards conclusions that are achievable. The technological and scientific levels attained in many African countries are low when compared with levels attained in other, developed countries. Africa, and in particular Nigeria, has natural resources but lacks trained skilled human resources. Most African countries including Nigeria were steadily developing their human resources in the post-independence era but poorly planned schemes and poor management, and sometimes inconsistent policies, have depleted its human resources. Thus, today Nigeria continues to lose both its trained and skilled manpower, a phenomenon referred to as ‘brain drain’, and its natural resources to better-managed regions and meanwhile continues to remain underdeveloped.

Women

A basic premise of this paper is that women, who constitute more than 50% of the population of Nigeria, are still unable to contribute meaningfully to the development of the country for reasons of illiteracy and poverty. These are two major problems that a well-planned and sustained programme of science education and women in science can change.

There is over 62% adult illiteracy among women. There is also an average of 55% of girls in schools, but while some states have a female population attending school of 90%, several others have 17% of females in school. Statistics of the population in 1996 showed that for school-age grade 6-11 years, 12-17 years, 18-22 years numbers were respectively 18.7 million, 13.8 million and 9.5 million. Of these, only 18.3% of the pupils were in primary school, less than 14% of the pupils of that age grade were in secondary schools and approximately 9% were in tertiary institutions. Within these populations, there is a high drop-out rate of females from educational institutions. It may be concluded that the country is building up at a fast rate a large population of unskilled and illiterate persons.

It is useful to note that roughly 20% of university students are female, though fewer than 7% are women in science, technology or related fields. Within the science field, on the whole there are more females in the biological sciences than in the physical and mathematical sciences. More women are studying the social sciences and the rate of female admissions in education and economics is increasing. But still a low percentage of the school age cohort is in school. How does the Third World Organization for Women in Science (TWOWS) enter into this equation in its search for a solution that would make for national transformation?

Women who conduct research in science are mainly in the universities and these are the members of TWOWS. Although Nigeria has 16 research centres, Nigeria has over 500 women scientists as members of TWOWS. Women are discriminated against in employment and often are under-employed. They are schemed out of decision-making places and suffer segregation, as they are usually employed in lower status executive jobs. They also carry out the unpaid family work.

TWOWS could perhaps set a few targets for the next decade and aim to have 80% of adult female literacy and women capable of accessing health services and other social amenities easily and by themselves. Some 90% or more should possess useful skills that enable them to participate actively in a modern economy. At least 50% of all women should be actively involved in issues such as good governance and the economy and should be able to demand social services that benefit them such as education, health facilities, a good network of good roads, an affordable home, affordable telephone services, good drinking water, nutritious food at affordable prices, etc. It is a major role that TWOWS can play in galvanizing women into increasing first the numbers of literate women and secondly the numbers who think scientifically, and bring about the needed transformation.

TWOWS, an effective engine for transformation

This paper proposes the following roles for achieving these targets because the level that women attain in any of the developing countries will determine the level of development that country can also attain.

Take the example of the USA, which enacted various laws that established agricultural and mechanical arts colleges and experimental stations. Such laws linked the state colleges, the experimental stations and farmers. These linkages helped to develop agriculture, ensuring that science, basic technical skills and tools were developed to meet the needs of the farmers and industrialists. University departments and the experimental stations were established by law and thus it was mandatory for states to ensure that people could enjoy the benefits of university outreach research programmes in agriculture and technology and use these as needed.

TWOWS must accept the task of advocacy by lobbying to enact laws that ensure effective linkages in research between academic higher-learning institutions, industry and agriculture. Such linkages would promote pure research but should also use applied research extension programmes to work in agriculture, food technology generally, education, health, water, communications, transportation, electricity and infrastructures.

Basic to women's development are literacy and agriculture. TWOWS must further lobby to enact laws which compel governments to establish experimental farming stations that are outreach research programmes in those areas which affect the common man.

Poverty is the major source of conflict (absence of peace) in many developing countries. Outreach research programmes that produce applications and programmes that teach skills and/or promote agriculture and literacy would alleviate poverty in rural and urban areas. With alleviation of poverty more girls will remain in school. As more girls are retained in school, more will complete the necessary basics to qualify for entry into further education. TWOWS must develop an advocacy role to retain more girls in schools to study science. It must project clear plans for research among members so as to attract more women into research in order to help plug the brain drain.

TWOWS should build units in every university and polytechnic to link the central office of TWOWS and should be a clearing house for research, with linkages with United Nations bodies, etc., and an executive arm that develops ideas, initiates projects and influences government as an advocacy instrument. It also encourages development of women through seminars that work on strategies and tasks for change and transformation. TWOWS would then not just be a body for pure science but one which also recognizes the present level of women and is prepared to work with them and uplift them.

TWOWS must assist in making the science curriculum relevant and useful to girls in school. But it is also necessary to attract girls to remain in school and study science so as to develop into young scientists. TWOWS should have a major activity screening the examination results at pre-university levels and thus make new plans for improving girls' education through guidance and counselling services. Where possible it should establish special science schools and classes for girls so as to increase the number of young women scientists needed to build a critical mass of women scientists. With such a critical mass more women scientists can aspire to and actually become women decision-makers on major decision-making bodies in science, technology, economics, social sciences, education and politics. It must ensure that women are integrated in and saturated with science, science applications and scientific and logical thinking. This can be safely and perhaps more interestingly done through linking women's activities to science and literacy through food technology and by applying scientific methods to indigenous technology: cloths, oils, foods, etc.

TWOWS must have a complete database of women in science (i.e. to assist it to make useful recommendations for women) to fill vacancies in public or private areas of work as the need arises.

General conclusion

Women are eager to learn, especially now that many come in contact with the new technology even within refugee camps. Television, radio and their children make them understand that changes are taking place. There is no need to repeat the French or Russian revolutions in Africa.

Rather, an organization like TWOWS has an opportunity to introduce useful scientific information at the grassroots level which could help enrich the lives of women, build up their confidence and self-reliance and assist them to gain control over their environment. As women gain measures of control over their environment, they will assist their countries in making the needed transformation.

Principles and strategies for integrating gender equity in S&T policies: a debate in progress

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The interest in understanding and promoting women's participation in science and technology (S&T) is a rather new phenomenon in Latin American academic institutions and activist groups working towards gender equality. For more than three decades, other issues related to discrimination against women in society, such as development, poverty, education, employment, health, legal rights and political participation, built the agenda of a wide and heterogeneous social and cultural regional movement. An enormous amount of new knowledge, innovative social practices, organizational experiences and legal and educational reforms informed by gender analysis were produced in those years, contributing to generate public awareness of the need to remove gender discrimination from societies, as well as producing a critical mass of researchers involved in women's gender studies and women's non-governmental organizations (NGOs).

This accumulative social and cultural experience, the increasing number of women in S&T careers, the recognition of the profound and rapid changes in this field and its influence on everyday life, and finally the preparation and development of the United Nations Fourth World Conference on Women held in Beijing, China, in 1995, created the conditions for recognizing the importance of systematically addressing women's participation and contribution to the production and utilization of S&T. However, it is important to notice that the Platform for Action that came out of the Beijing Conference did not include a complete chapter on women and S&T, although several dimensions and recommendations related to this area were mentioned in other chapters such as education, economy and poverty.

In recent years several meetings, publications and debates promoted at the national, regional and international levels have contributed to the identification of the main problems in women's relationship with S&T, in defining its causes and consequences, not only for women but also for society and for science, and proposing different strategies for achieving gender equity in this field.

Within this process, it is relevant to mention the role played by UNESCO in promoting and organizing six associated regional meetings[1]. The Latin American meeting, held in Bariloche, Argentina, in October 1998, was attended by some 250 participants from 11 countries and its contributions allowed us to understand common concerns as well as specific limitations and demands that need to be considered in future actions.

The aim of this presentation is to show a 'map' of the different stages or phases in the process of understanding and changing women's relationship with S&T which can be seen, not only in Latin America but also internationally. Each of these stages is based on a different political, ethical and theoretical definition of the main problems to address in this area and on the kind of solutions to undertake to solve it. Basically I'm interested in showing what kind of proposals emerge from each stage for planning a gender-sensitive science education and in general for the development of gender policies in this field.

In a certain way this map reflects a historical development of the utilization of a gender perspective in S&T, but must not be considered in an evolutionary manner. As in many other aspects of reality that have been interpreted with 'gender lenses', nowadays there is a coexistence of different conceptual approaches and strategies to improve women's contribution to science. However since this is a time to move from words to actions, and also to think of the long term and of sustainable strategies and policies for achieving complete gender equity in this fundamental area, I hope the comprehension of these different perspectives and conditions might help to make such decisions. Finally and based on our own experience of integrating gender equity in the National Scientific and Technological Policy, I suggest some fundamental points to be considered for this purpose.

Where to go

The few small-scale experiences that are being developed in this field in Latin America and experiences in other regions as well as the discussions made by researchers, policy-makers and activists show that, in order to produce real change, there is a need for:

- active policies and programmes addressing all dimensions of gender inequality in S&T, both at the national and regional levels;
- political will of national and international organizations;
- financial investment in policies and programmes;
- participation of different sectors (governments, universities, women's NGOs, private sector, women leaders in politics and business, international agencies and donors);
- trained human resources in gender planning and evaluation;

Table 1. **Stages in linking gender concepts and perspectives with S&T**

Problem definitions	Perspective	Objectives	Measures/actions	Principles
Unequal participation of women as students, teachers and professionals in S&T Horizontal and vertical gender segregation in different areas and at different levels of S&T Unequal access of all women to S&T knowledge	'Deficit model' (women as a minority group at a social disadvantage) **Compensatory strategy**	Promote equal opportunities for women's access to and participation in S&T	Educational programmes scholarships, grants, and other incentives Training programmes, provision of new technologies for all women, creation of networks	Equal opportunities Full women's participation in development
Power relations and socio-economic and political conditions in the structure and substance of S&T Dominant paradigms and an epistemic bias in S&T discourses and practices (androcentrism, sexism) Devaluation of women's knowledge, skills and S&T culture	'Difference model' (revaluing women's contributions to and visions of S&T) **Critical strategy**	Equal participation of women in the definition of problems, priorities, methodologies and uses of S&T Creation of new scientific paradigms (integration of women's and other groups' ways of knowing, producing and using S&T) Deconstructing positivistic premises of science (value-free, universalism)	Research and academic debates, from a gender perspective of the epistemology of S&T Build new curricula, textbooks, pedagogies and promote gender-fair teacher attitudes, expectations and values Teachers and students as critical readers and producers of creative scientific and theological knowledge	* Inclusivity * Diversity * Empowerment as keys for **Better science** **Human development**
Achieve a better understanding of: *the gendered nature of S&T throughout history and in different cultures *how S&T create, reproduce and also change gender relations in society * the relations between gender, ethnicity, class, age, etc. *how gender equity improves S&T and is a substantial component of human development, democracy and social justice	**Systemic strategy** (from 'margin to centre')	Mainstreaming gender analysis and gender equity goals in S&T policies and programmes at the national, regional and international levels	Promote and support research on gender relations in different dimensions and disciplines Incorporate gender analysis in planning and evaluation of data and impacts of projects and policies Develop gender-sensitive science education at all levels, in the formal and non-formal systems Assure equal participation of women and men in all fields and at all levels of responsibility in S&T Affirmative action and other measures to remove deep and subtle obstacles preventing women´s full access and professional development in S&T *Create friendly working environments to facilitate the integration of professional and personal life for both women and men working in S&T	Mainstreaming gender analysis in all policies and programmes in this field Assure its implementation and monitoring

- long-term projects (state policies instead of government initiatives);
- creation of new indicators and continual monitoring systems;
- regional and inter-regional exchange and cooperation;
- raising public awareness and support of this issue.

Note

1. See note on p. 347.

The role of women in science for sustainable human development

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Female and male scientists cooperated at the UNESCO European Regional Conference on Women in Science[1]. The Conference overcame the traditional approaches in the struggle for recognition of women by declaring the goals which are equally important for men and women, but which will be reached only if both genders develop their creativity to the maximum, thus achieving quality through equality.

The essential role of women scientists in changing the 'global intolerables' into developmental opportunities was stressed: for turning population explosion into reproductive health; poverty and environmental degradation into sustainable human development; and violence into peace and cooperation. All the knowledge and creativity of both men and women in science are needed to bring about this change.

Even more, science alone cannot do it. For economic development, knowledge has to be further developed into know-how and applied in entrepreneurial activities. For integrated, balanced social development, knowledge has to be combined with cultural values (local, national, global) to reach the level of wisdom which alone can bridge the enormous gaps between our starting points and our ambitious goals. Reaching these goals is, however, not only essential for development, but is the condition for survival.

This new approach to engaging women does not, however, mean that stressing women's rights with identification of, and struggle against, female discrimination is less important. Neglecting the talent, the creative power and the social harmonizing potential of women – i.e. half of the world's population – is therefore an unforgivable waste. It has to be considered as the fifth – or maybe the first – of the 'global intolerables', as a most serious social disease. Examples of this disease were discussed at the Conference: deficit of women scientists in top-level university management and professorial posts; practical exclusion of women scientists in development policy creation; discrimination against women scientists in recruitment for leading positions in research; feminization of professions with low resources, status and capacity to generate excellence in research and education; and ignoring women scientists in delivering awards and other forms of recognition. Among the reasons, obsolete attitudes to the social role of women, direct and indirect discrimination based on exploitation, inadequate family education and absence of proper child care provision were stressed.

Women scientists' contribution to reproductive health

Population problems are too complex to be dealt with here in detail – they deserve, and get, attention at numerous specialized meetings. However, we can expose two major problems:

- rapid population growth in many countries which, mainly due to poverty, cannot cope with it, resulting in growing unemployment, decreasing standard of living, and – not rarely – in social unrest, even in violence;
- in most countries, an ageing of the population, causing – if conditions are not adapted to this trend – serious economic problems. These bring about social conflicts between the ever thinner active and the expanding retired population, which usually leads to the impoverishment of the latter.

Full equality of women is the *conditio sine qua non* for solving any of the population problems. Women in science need to take more initiative in research for a balanced population growth and application of its results, particularly by educating men and women for reproductive health. They also should do more for improving the socio-cultural value system by emphasizing values which are usually (but not exclusively) assigned primarily to women: care for life and home, compassion, family spirit, protection of children and respect for old people. The highly developed part of the world should learn these from those developing countries where wider family and social coherence are still highly respected.

Women scientists' role against poverty and environmental degradation

Poverty and environmental degradation are the most serious global problems. Gross domestic product (GDP) per capita extends from less than US$ 300 to over US$ 30 000. However, the countries with high GDP are but few. The vast majority of the global population is poor. Global aid is even poorer: less than 2% of 'investment' in armaments.

Women in science should take the lead in the struggle against poverty. Two tasks for women are very clear. The first one is insisting on much stronger support for development in underdeveloped regions. In Europe, so often burdened with a eurocentric vision, we should not forget that today – due to the globalization processes – the world is one and no region can live in peace if others are starving.

The second task is even more obvious: the clarification of the fictitious and widespread idea that global wealth could be achieved by a simple redistribution of wealth. If we divide today's global GDP by the global population, the result would be poverty for all. The answer (women in science should stress it more strongly) is an intensified creation of wealth by developing new, environmentally friendly processes and products of higher quality, and more efficient economic and social management, leading to sustainable development. Because knowledge is the main power for development: the global GDP has grown sixfold in the last half-century – in large part due to increasing basic knowledge applied in know-how.

This is, of course, equally the task of men and women in science. However, it can be achieved only by a more intensive engagement of scientists in the transfer of knowledge into processes of work and decision-making. The existing academic value system is not promising since it is mainly competition oriented (e.g. counting numbers of publications in scientific journals with a high impact factor, counting citations and similar). What we need for an efficient transfer of knowledge into practice is less competition and more cooperation – in group work and internationally. Or, perhaps: competitive cooperation for achieving common goals.

Women are usually less ambitiously competitive, which is a disadvantage in this competitive academic promotion system. However, women in science often have more talent for reaching other values which are needed today and even more tomorrow. These values are particularly development of a group spirit and group intelligence, development of leadership in a *primus inter pares* approach, transfer of knowledge into processes of production and decision-making, increasing the knowledge component for all types of work, enriching objective knowledge with cultural values. All these have to be introduced into academic life if scientists are to be encouraged to take the lead towards sustainable development. If these approaches, so much needed for the whole society, are properly respected and included in the academic value system, women in science will have no problem proving their scientific quality and equality.

Women in science for sustainable human development

Sustainable human development is all too often understood as being just the need to limit consumption for the protection of the environment. In practice, most of the global population is not enthusiastic about these requirements. The richer ones are not pleased with limitations and the poor oppose these demands with the well-justified statement that they have lived at the limits of consumption for a long time and have the right to take a greater share in future. The model of limits does not create enthusiasm.

Another approach to sustainable development is needed. 'Development' must be the optimistic promise of a better life for all people. 'Human' should mean another value system giving more weight to non-material richness and solidarity, including a deeper responsibility of mankind towards nature. 'Sustainable' should mean primarily better quality which will allow higher standards of living to be reached with lower consumption. 'Sustainable human development' should therefore be understood as progress through increasing quality in every human activity.

To increase quality, we need better knowledge. We need achievements in the natural sciences and technology, in social sciences and humanities. This means a more efficient contribution by every country to the global treasury of science, but also integration of global knowledge into national and local expertise. To recognize quality in human terms, we need an improved value system. Only knowledge interwoven with values creates wisdom. While science remains the major source of new knowledge, the value system is primarily based on culture. We have to rethink and redefine development, productivity and wealth. We have to strengthen, or introduce, values which will foster care for the environment, health, stability, beauty and harmony.

The specific role of women, particularly in science, is linking tradition with change. This implies values which support not only accepting and coping with changes, but also mastering – and creating – them in cultural humanist terms, i.e. for the benefit of the individual, the local, regional and global society, and for harmony in nature, in which humans need to become a less-disturbing element.

Women scientists' role for peace and cooperation

We all speak of the global society as being a more harmonious society which seems to appear on the horizon, or at least in our vision. However, as we well know, the way towards it demands serious efforts, even at the level of a developed region like Europe. The collapse of totalitarian *imperia* is promising, but also implies new threats. The liberated nations which should be integrated in new, democratic systems are also in danger of going in the opposite direction: splitting into ethnic groups with emphasis on nationalism, or into religious groups forcing fundamentalism. Both are leading to violence and wars.

Women should make clear that efforts to abandon prejudices and develop tolerance are not sufficient. Women, who are usually less hierarchically oriented, should not be afraid to declare the idea of the 'main nation' or 'main religion' tolerating 'minorities' as wrong. History has plenty of examples that any monoculture – from agriculture to society – is prone to diseases. Tolerance should therefore be replaced by education for respect and love of differences in cultures and in opinions.

Women scientists launching R&D-based learning

Since innovative approaches need to become a standard part of education for the 21st century, women in science (bearing in mind that the majority of teachers are women) are particularly responsible for introducing education reforms based on all four pillars defined by the Commission on Education for the Twenty-first Century:

- *learning to know:* learning to learn, strengthening the power of concentration, developing a critical mind, training of memory for selection of appropriate information;
- *learning to do:* linking knowledge with skills, developing innovative approaches and entrepreneurial abilities, work planning, increasing the knowledge component of every activity, developing group intelligence and competition to achieve common goals;
- *learning to be:* developing intellectual and physical abilities, scientific reasoning, imagination and creativity, communication skills, sensitivity, aesthetics, responsibility;
- *learning to live together:* behaving as an individual, family and community member, citizen, producer, inventor, creative dreamer.

Science and technology are increasingly dynamic and their results are applied with much shorter lead-times than decades ago. We cannot learn what we will need in 10 years' time, since this might be discovered only two to three years before. But we can learn to develop an inquiring approach. In tertiary education, development of R&D-based learning is a crucial task. Many universities give priority to research and pay insufficient attention to education. Yet, it is education which will be in the next decades the decisive factor for development. Women in science should use this opportunity and take the initiative in this – often underestimated – field.

Conclusion

A much stronger engagement by women scientists in discovering and disseminating new knowledge and in development of its economic potential, as well as of its social harmonizing power, is crucial for sustainable human development. Women in science have to play an essential role in widening the mission of universities and other research organizations by developing them into centres of research, education and innovation. This engagement will be a very efficient way towards full equality of women and particularly women in science.

Women in general, and women scientists in particular, have the potential for making a major contribution to sustainable human development, particularly through their humanist understanding of the role of science and technology, solidarity in sharing their benefits, careful judgement of unwanted side-effects in applications of science on society and the environment, and – as leaders – ability to change ruthless competition into competitive cooperation for achieving common goals. It is high time we recognized that these women's talents are essential for today and the future, and should therefore be most welcome and carefully developed. It is the task of men and women to take measures to tap these talents – or, to be more precise, primarily the task of men, since they hold today the majority of decision-making positions.

Note

1. See note on p. 347.

Promoting science learning for girls and women: policies for human resources development

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Policy analysts generally agree that the education of girls and women is a good strategic investment because of the benefits that accrue to a country and to its long-term development. The impact of 'female education' on rates of maternal and infant mortality, population levels and other indicators has been documented. Yet policies to promote development have not been specifically linked to education in science and technology.

In view of women's unique roles within the family and community with regard to education, health-care giving and food security, their contribution is crucial to the future development of the countries of the world. While these issues have been acknowledged in the movement for women's rights and in the analysis and support of development initiatives, the role of science education for girls and women has not been specifically linked either to development or women's rights agendas.

Science in development

The connection between science, technology and major development concerns has been noted within countries, within the science community and by major development assistance funders. As countries face issues of providing adequate infrastructure, access to water, education, sufficient amounts of food, protection of the environment, freedom from disease and development of markets, the role of science and technology is regularly acknowledged. Yet the gender dimensions of science and technology for development have been less often recognized, even as women bear a disproportionate share of the responsibilities for attention to development concerns within the family and for the community.

Women and development

Since the First World Conference on Women sponsored by the United Nations, attention has focused on women's role in development. Yet it has been difficult to advance the notion of science and women's education in science as key aspects of enabling women to address personal, family, community, national and global concerns related to development. The most promising recent effort was that which came from the United Nations Commission on Science and Technology for Development (UNCSTD) in the elaboration of its contribution to the World Conference on Women held in Beijing. Delegates to UNCSTD, working collaboratively with a group of women scientists and engineers, formed an Advisory Group on Gender, Science, Technology and Development. This group, along with advisers and consultants, developed a work plan that led to the production of a scholarly document (*Missing Links*), a report and recommendations that were adopted by the United Nations Economic and Social Council (ECOSOC), and a follow-up plan to more intimately connect science, and education within science and engineering, to the women-in-development agenda.

Mainstreaming gender concerns

The articulation of transformative actions, promotion of *ad hoc* national committees to review their own status in relation to the challenges articulated in the transformative actions and the establishment and work of a Gender Advisory Board (GAB) to UNCSTD have ensured that efforts will continue to promote the connection of science to the agenda of women's development.

Several lessons emerge from the history of GAB that are important to ongoing efforts to mainstream gender concern:

- The need to expand the language of reform from one of women's rights to one that includes a focus on countries' long-term needs and the contribution that women can make to meeting these. Women and girls represent half of a country's intellectual assets. Since science and technology are important to countries' long-term development and prosperity, women, as half of the available talent pool, must be provided with the education and opportunities to contribute. Women in science and technology need to become part of the economic development planning agenda.
- The need to collect disaggregated data important for informing policy-makers of the current position of women and girls with regard to primary, secondary and tertiary education, enrolment and degrees in science and engineering, presence as teachers and faculty, and participation in the workforce.
- The need to promote universal literacy that includes attention to science, mathematics and technology.

Human resources development

A country's long-term future depends on its people, on whether they are provided with an education and opportunities to meet their immediate and long-term needs. The development of people needs to be expanded as a concept to include the development of women and girls – providing them with education needed to live and work in a world increasingly defined by science and technology.

S&T for development: the gender dimension

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It is indeed a great honour and a pleasure for me to speak today to such a distinguished gathering at this thematic meeting of the World Conference on Science. Our discussions today are devoted to a very important issue, namely the gender dimension of the use of science and technology (S&T) for development.

S&T offer developments that are promoting the world economy in many unimagined ways. They have a profound effect on the search for feasible pathways towards just and sustainable development strategies. S&T provide decision-makers with faithful and intelligible knowledge to better enable the formulation and selection of development policies. The experience of some countries that have achieved rapid and high rates of economic growth demonstrates clearly the critical role of factors associated with S&T-based competition.

Some developing countries have been able to join the industrialization process and they are experiencing remarkable growth rates, while others are not able to make comparable investments. In addition, current globalization tends to render some of them increasingly marginalized and almost excluded from the global economy.

Sustainable development does not automatically follow on from results of scientific research or technological acquisition. It depends on the efficient use and the proper allocation of the available scientific and technological resources to serve domestic needs. This requires strong endogenous managerial capabilities that would serve not only as a tool to carry on with the complex effort of converting research and information into economic growth, but also to identify the key problem areas of particular economies.

For developing countries to be able to engage effectively in the ongoing global restructuring process, they need to invest in their own scientific and technological base, including the development of human resources with appropriate skills to harness the potential of S&T to their own needs. In this respect, the priority required lies in one of the most basic factors for development, namely education in general, and S&T in particular. S&T capacity-building through educational measures and training of all available human resources, men and women, needs to be recognized as the indispensable component of any country's effort to mobilize S&T for the development of its society. However, unfortunately, in many developing countries, girls do not enjoy equal access to the formal education system. There are a number of obstacles to girls and women receiving S&T education and pursuing S&T careers. The disparity between women's and men's access to advanced S&T training and education is still pronounced and limits women's opportunities to acquire skills, improve the quality of their lives and gain access to employment. Through this, the country could be losing up to one half of its pool of national talent. Governments should recognize the need to maximize the creativity of all available human resources and create policies which foster and promote equitable access of both genders to S&T education and careers.

Key policies and plans for the use of S&T for development are formulated at the national level and are the consequence of countless decisions at several levels. This process of planning and decision-making needs to be sensitized to the gender aspect of development. Up till the present, S&T intervention for development has focused mainly on meeting men's needs. We can say that, in general, the impact of S&T on societies has not yet been uniformally beneficial. Women's concerns and interests still appear to be unrecognized. Failure to recognize the differential impact of technical change on the lives of men and women is likely to have a negative impact on the development process as a whole. The gender insensitivity of the use of S&T in development planning is well documented and is illustrated by several examples all over the world, particularly in developing countries. Allow me to bring to your attention a few examples in some selected sectors of development such as health, food security and energy. These sectors are greatly affected by the trends in some of the S&T areas in which there has been a remarkable growth in knowledge, namely biosciences, material sciences and information technology. They all have a tremendous technological potential and offer developments that are revolutionizing our present approaches to many fields. However, what distinguishes the biosciences is their intimate connection to agriculture, food security and health care, of great political and economic sensitivity and social importance.

Gender issues and health

Recent studies note that a contributing factor to many adult women's health problems appears to be a lifetime of gender discrimination. Girls are likely to suffer from a wide variety of discriminatory practices; they get less health care and nutritional support. Gender inequality in health care is one of the root causes of other health problems. It also affects some commonly used national health indicators, such as morbidity and mortality rates, which are designed to monitor progress in general.

Scientific research in the areas of health behaviour and health systems shows that gender roles are among the non-biomedical factors that determine progress of illness and eventual outcome of medical treatment. Scientists have noted that the effect of tropical diseases and opportunities for treatment can be quite different for men and women. In present health research and statistics, the gender perspective is changing conventional scientific paradigms and is introducing gender roles as a new and significant social variable. This has lead to pioneering research in epidemiological, biological and health behaviour studies.

In brief, development should take care of everyone's health problems. Gender health concerns must be considered within an overall S&T health policy if such national policies are to have any real impact.

Gender issues and food security

Food security is not just a human need but has become an issue of basic human rights. Food production is intimately tied to S&T-based agricultural systems that ensure high yields and sustainable productivity. Gender plays an important role in these agricultural production systems. However, agricultural policies have usually up till now viewed men as the farmers. Introduction of modern agricultural technology primarily aims at male tasks and is used by men.

Establishing food security calls for strategies in which grassroots communities own, control and play effective roles in technological choices and development. Technology can be of sustainable use only if it is compatible with prevailing systems, cultural practices and the socio-economic resource base. Sustainable agricultural and food security demand strategic interaction between traditional and modern systems. The fact that women are the custodians and the primary holders of local knowledge and know-how about food production technology has not been recognized by new S&T innovations. Women's indigenous knowledge has usually been marginalized by the prevailing gender bias of S&T, despite the fact that it contains a great deal of precise and useful S&T information which has evolved within communities over centuries of trial and error. However, how to build on and use women's knowledge base, so that modern S&T can benefit from it, remains a problem and needs to be addressed.

Gender issues and energy policies

Energy is an essential component of modern economies and a growing energy supply is requisite to raising standards of living. A significant proportion of the global economy is dedicated to providing energy services in the form of cooking, heating, motor appliances and industrial processes. The implications of S&T advancements and modern energy policies for livelihood are gender related. Energy policy initiatives in the late 1970s and 1980s identified and described the critical role played by women as managers and producers of energy not only in the household but also in other sectors. They play a dominant role in agriculture and many energy-intensive small and medium-sized enterprises and home industries, which at present account for the vast majority of production outside the formal sector and are central to economic survival outside the transnational sector in many developing countries. However, energy planners have not paid much attention to such roles. Women are marginalized by development programmes related to energy resource management and their roles in the energy sector have been viewed almost exclusively in relation to domestic energy use only and 'did not go beyond the stove mentality'. A number of United Nations initiatives over the years have been ineffective in advancing women's position with respect to energy issues.

Women have more contributions to make to energy policies at all levels including implementation of research and development. They are instrumental actors in developing innovative energy strategies and in disseminating new ideas at all levels. Involvement of women as both contributors to and beneficiaries of energy measures and training, technology development, policy- and decision-making and implementation need to be addressed.

Development is gender-specific and the effect of S&T trends on development policies is growing and will continue to do so. It is important that S&T policies recognize this gender-specific nature of development and respond to the needs and aspirations of both men and women equitably. The objective of such policies must be to maximize the benefits to be derived from S&T for all members of society. Gender-biased S&T interventions for development, which are designed only from the perspective of men's lives, cannot generate sustainable human development for communities at large.

Allow me to conclude by emphasizing that gender planning is not an end in itself but a means of bringing to bear a different perspective and a new intellectual dimension which will be reflected in the nature of the development process to render it to a development that does not generate merely growth but growth with justice and equity.

Thematic meeting report

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The thematic meeting on mainstreaming women in science received the reports from six regional meetings on women and gender, science and technology associated with the World Conference on Science[1]. An NGO *Declaration on Women and Science* was also available. The present report is based on the aforementioned documents as well as on the panel presentations and the contributions by more than 30 speakers from the floor at the thematic meeting.

The nature of the problem

Although differing in the details, there was similar evidence from all regions of the world of the nature of the problem and possible solutions. There was agreement on the basic facts:

- In many countries, especially in Africa, fewer girls than boys have access to primary education and, of those children that do have access, fewer girls than boys learn about science.
- In many countries, fewer girls than boys study scientific and technological subjects in both secondary and tertiary education.
- In many countries, fewer women than men pursue scientific or technological careers and far fewer reach the top professional, managerial or policy-making positions.
- Technological change, especially that designed to improve the quality of life in rural areas in developing countries, has been more directed towards the tasks that men perform than to the tasks women perform, both in and outside the household. Development programmes frequently have not taken this gender dimension into account.
- Men and women are repositories of different components of indigenous knowledge.
- Not all countries are in the same situation. A few, especially those in Eastern Europe and some in South-East Asia, have rough parity between those men and women who obtain professional qualifications in science and engineering and who enter scientific and technical careers. But even in these countries the most senior jobs still go disproportionately to men.
- There is some statistical evidence to suggest that the situation is improving, especially with regard to the proportion of female students who study science and engineering in universities. But there was widespread agreement that country comparisons over time are hindered by the paucity of gender-disaggregated statistical data which is comparable, timely and reliable.

Reasons for the problem

There was more divergence of opinion on the reasons behind these facts. Some of the divergence was due to the different situations which exist in different countries and regions of the world. They included cultural differences which in some countries serve to discourage girls from studying science in schools or universities, and from pursuing scientific careers. Other reasons advanced were discrimination, career interruptions due to childbirth and family responsibilities, gender-stereotyping of science and technology, and the relative lack of women in policy- and decision-making positions. It was also recognized that the full gender dimension of science and its impact on society was imperfectly understood and warranted further study and research.

Does it matter?

Does it matter if the above differences between men and women exist? The meeting was in no doubt that it did matter and for the following reasons:

- *Human rights and social justice*. All individuals should have equality of opportunity to a science education and to a scientific career, and women and men should benefit equally from advances in science and technology.
- *Scientific and economic reasons*. If women are not given equal opportunity to become scientists and engineers then a country denies itself its full complement of scientifically creative minds. This can be a serious handicap both to the development of science and to the generation of wealth in an increasingly competitive world.
- *Social and economic reasons*. Equal access of both women and men to scientific and technical resources and education will benefit their participation in productive and reproductive tasks and contribute to the sharing of roles and responsibilities both within and outside the home.
- *Enriching the pool of insights and motivations*. Some women, it was suggested, bring different insights, values, motivations and methods of work to their scientific jobs than do most men and other women. The inclusion of more women in science will enrich the total pool of talents, insights and motivations, and increase the probability that science will serve the needs of all humanity.

In a few countries in the world there appear to be few major obstacles to women pursuing rewarding careers in science and technology. In most of the world, however, there are major problems. Overcoming these obstacles and problems was seen as one of the most important challenges facing science in the 21st century. It is at the heart of the 'new commitment' called for by the conference organizers.

What can be done to overcome the problems?

The reports from the regional meetings and presentations to the thematic meeting yielded many detailed suggestions on what needs to be done to overcome the problems. The suggestions fell into two main categories following the structure of the World Conference on Science. These were actions to highlight and improve the opportunities for women to contribute further to science, and actions to ensure that science impacted positively on the lives of women and men equitably.

Within the first category were many suggestions relating to education in science for girls and women at all levels, as well as ideas on how the obstacles facing women who pursue scientific careers might be overcome. Within the second category were suggestions aimed at making more explicit the gender dimension of sustainable development, and ensuring that this gender dimension is taken into account in determining research priorities and designing development programmes. The gender dimension pervades most aspects of the way in which science impacts on society, including agriculture, health, environment, industry, employment, local knowledge systems and many ethical issues.

Although there is a need for more research on the topic of gender and science, there is enough already known for action to be taken now. One of the main messages from the thematic meeting was that the *status quo* is not an option. Change is urgently required. Action needs to be taken by many organizations and parts of society. These will include national governments, international organizations, the scientific community, non-governmental organizations (NGOs), employers and individuals. Action must be targeted at the particular needs of each country. To define these needs and to develop appropriate action plans for solving local problems, each government should establish its own mechanisms. Donor agencies can then provide assistance to help implement the national plans and strategies.

The regional associated meetings organized by UNESCO have clearly demonstrated the value of regional approaches, especially for developing new science curricula which are not gender stereotyped. But regional and global action can go well beyond these proposals. There is a need for a major campaign, which UNESCO and UNIFEM (the United Nations Development Fund for Women) should organize, to alert policy-makers and educators and parents in all countries to the critical importance of gender and science. NGOs such as TWOWS and OFAN (the Once and Future Action Network – of international NGOs) can also play an important role in helping with this campaign and in promoting networking. The Internet is already proving a useful tool in this regard and its use should be expanded.

In brief, the thematic meeting concluded that, in nearly all aspects of science and its impact on society, there is a gender dimension. This dimension needs to be recognized, made explicit, and action taken to ensure that men and women can contribute equally to the task of maximizing the benefits to society of science and minimizing its harmful effects. It was noted by many people at the meeting that the issue of gender and science is not just an issue for women alone. It is of vital importance for both men and women. Some participants and panellists, however, felt that the issue was a women's issue and could best be solved by forming women's groups to lobby and take political action. Some felt that the choice of a male rapporteur was inappropriate. Others felt that gender equity in science would be achieved more quickly if more men understood the issues. They would have preferred to see a more equitable balance of women and men on the panel (only one out of seven speakers was male) and more men participating in the thematic meeting (only 20 out of over 120 participants were men).

Some participants in the Conference wanted to include the issues of women in science in the same category as the issues of minorities and disadvantaged groups in science. There was a strong consensus at the thematic meeting that this would be fundamentally wrong. Women are not a minority, nor should they be treated as a disadvantaged group. Their full participation in science and technology is a necessary condition for achieving sustainable human development.

Postscript

Following the thematic meeting, a set of proposals was sent by the Rapporteur and Chair to the Conference Drafting Group suggesting changes to the draft *Declaration* and draft *Science Agenda*. Most of these changes were incorporated in the final texts, including a new paragraph in the *Science Agenda* (paragraph no. 90, *Science Agenda – Framework for Action*, p. 476 ff. of this same volume) which drew heavily on the discussions at the thematic meeting.

Note

1. The organizers of these UNESCO regional meetings were: Latin America: Argentina, Marta Borda and Gloria Bonder; Europe: Slovenia, Zofija Klemen-Krek; Asia-Pacific: Australia, Minella Alarcon; Africa: Burkina-Faso, Renée Clair; Mediterranean Area: Italy, Maria-Paola Chiesa; Arab countries: United Arab Emirates, N. Saleh. The reports may be consulted at: www.unesco.org/science/wcs/meetings/meeting.htm

Basic science and society

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Modern society needs basic science for several reasons, of which the most important are:

- Science has provided humanity with a new view of the world (*Weltbild*). Questions such as what is matter, what is life and what is consciousness have found new answers or are being extensively studied. Why does order exist in nature, what is the position of man in the cosmos or how did evolution develop? Answers, even if never definite, to such questions lead to a better understanding of how human beings are embedded in nature and can even contribute to our sense of life. Science helps to avoid a dangerous transition to irrationalism which becomes manifest by the spreading belief in astrology, post-modern relativism and the springing-up of sects.
- Basic science and research of today is the technology of tomorrow, which is one of the crucial elements of the modern economy and hence of the welfare of society. Without it, the majority of people would still have to use most of their time just to satisfy their basic needs as far as nutrition, shelter and heating are concerned. The abolishment of slavery and the participation of a large fraction of humanity in cultural activities would not have been possible without science and technology. Curiosity-driven research has been the basis for electricity, radio and television, of energy production and saving, of many diagnostic and therapeutic methods in medicine, etc., which are essential for our modern lifestyle. For basic science to thrive, long-term commitments by governments and industry are needed, which are indispensable for the creation of new ideas and visions. Short-term benefits, as expressed by the 'shareholders' value', are the wrong criteria leading to widespread abandonment of basic research in industry, stagnation as far as new technologies are concerned and loss of competitiveness.
- Science and politics. International cooperation and in particular large projects contribute to a better mutual understanding of people from different cultures, religions and political systems and they create confidence. Such achievements in science radiate to other domains, for example when agreements in scientific collaboration, sometimes involving politicians at the highest level, can serve as models for other governmental contracts. They help to bring developing countries to the level of industrialized nations and spread the recognition of general human values. They promote peace. Examples of large-scale cooperation created under the auspices of UNESCO are the European Laboratory for Particle Physics (CERN), which has extended its activities to the whole world, the Auger project to explore cosmic rays and presently the plan to create a centre of excellence in the Middle East/Mediterranean Region with a synchrotron light facility as its major facility.

At an International Workshop on the Future of Physics and Society, which was associated with the World Conference on Science and which took place at Debrecen, Hungary, on 4-6 March 1999, some actions were recommended, some of which refer to science in general[1].

The most important recommended actions are to:

- affirm the vital importance of basic science and the need to protect and support curiosity-led science requiring steady, long-term support;
- invest substantial effort to educate and inform the public. A guideline should be established to make about 1% of funds spent on research available for public awareness-building;
- provide substantial support for the improvement of teaching of science throughout the world, at all levels from school to university. In addition, support is required for teachers, for example by enhancing their prestige and providing continuing education and personal development. Scientific subjects should be taught by persons who have been trained to become teachers in the subject. Information on curricula in different countries should be established and made widely accessible;
- explore ways of establishing a recognized authoritative and impartial international body, set up under the auspices of the United Nations, UNESCO or ICSU, to adjudicate damaging disputes involving scientific issues. In view of the fact that scientific matters are often complicated, difficult to understand by the general public and sometimes

presented in a distorted way by the scientists involved or by the media, detrimental disputes arise with damaging consequences for science and society. Examples are environmental problems (climatic changes), nuclear safety, genetic engineering or cold fusion. The proposal is made in order to avoid such damage or at least to reduce it as much as possible. The new body would investigate the extent to which claims are based upon established science or are simply ungrounded opinion, perhaps influenced by pressure groups. This would provide an authoritative scientific basis for important political decisions;

- take special measures to ensure the free movement of scientists. In particular, UNESCO should encourage governments to facilitate the issuing of visas for scientists if such are required;
- establish guidelines linking research and development (R&D) expenditure to gross national product (GNP) at a level appropriate to the economic state of each country, for the benefit of the long-term health of science. UNESCO should establish a committee to make the necessary recommendations.

In the discussion of this thematic meeting, these recommendations were largely agreed upon and exploring possibilities for their realization was considered to be an important follow-up to the World Conference on Science.

Note

1. The full report may be accessed at http://xxx.lanl.gov, preprint physics/9904013; see also www.atomki.hu/~future/index.html and *Physics World* June 1999, p. 15. A summary report may be accessed at: http://www.unesco.org/science/wcs/meetings/eur_debrecen_99.htm

What does it mean, a social contract for science?

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The notion of 'contract'

The idea of a social contract for science is well suited to expressing two needs that are both legitimate, but can be conflicting practically:

- the need to secure a substantial freedom for science;
- the need to make the development of science compatible with other social requirements that could impose certain limitations on this freedom.

In fact, the notion of contract implies agreement, understanding and acceptance (instead of coercion); it entails reciprocal satisfaction of certain needs as compensation for certain positive services offered, and also for certain accepted limitations. Therefore, if we really accept the intellectual approach implicit in the concept of an (equitable) contract, we can overcome that attitude of struggle and mutual diffidence that has too often characterized the debates regarding the legitimacy of imposing certain limitations, or the compulsory realization of certain goals, on science and technology in the name of the needs or fears of society.

The peculiarities of a 'social' contract

We want to declare explicitly, in order to avoid misunderstandings, that the idea of a social contact we are going to explore here is very different from the historical notion of social contract that was elaborated by several authors especially in the 18th century. According to that old meaning, a social contract was the idealized instrument by means of which humans come to constitute a political society. According to the new meaning we are proposing here, a social contract is a contract of a specific social nature. The fact that a contract is social entails certain fundamental aspects: first, that partners of this contract are social institutions or agencies and not individual persons (not even 'juridical persons'); secondly, that the object of the contract is of a global nature – it is something like a common good that the different partners commit themselves to promote.

Both conditions are essential, for a contract could not be considered as really social simply because it does not concern single individuals but collective agencies or institutions, and this because collective interests (of a particular collectivity) are not by necessity interests of society considered as a whole. In other words, many forms of collective egoism can be imposed by contracts that simply take into account the needs of certain particular and privileged collective agencies or institutions. On the contrary, if the global interest of society is also duly recognized and respected, even the special advantages that each agency can expect from the contract are not the effect of bilateral obligations but of an overall optimization of the common good.

From the above considerations also follows a consequence regarding the special methodology necessary for elaborating such a contract. Indeed the social nature of this contract imposes that it be the result of a participative elaboration, that is, of an effort for making explicit the different general interests of society in which all citizens must be and feel involved, must be capable of evaluating proposals and arguments, and must be in the position of expressing their preferences in democratic discussion and decision-making. This is tantamount to recognizing that a social contract must be, in the final analysis, the result of a democratically taken political decision, and not the simple result of negotiations among the most influential or powerful parties.

A systems-theoretic approach

The intellectual background for the shaping of this contract is a systems-theoretic view of society, that is: society is a global system, embedded in a complex environment and articulated in several open and adaptive subsystems. A systems-theoretic approach is the appropriate framework within which the ideal-typical features of a social contract can be outlined. According to such an approach the adequate functioning of each subsystem must be compatible with, and even instrumental to:

- a similar adequate functioning of all the other subsystems;
- the attainment of the overall goals of the global system;
- the preservation of the various environmental conditions.

This conceptual framework is at variance with the deeply individualistic mentality that permeates our culture, and advocates a holistic way of thinking to which we are still very little accustomed. It is already implicit, however, in several methodological approaches that are adopted in certain fields of our science and our practical life, whenever problems of complexity, of functionality, of multifactoriality must be mastered. General Systems Theory has already provided useful tools for treating such problems at a local level, but it must become a much broader intellectual instrument for tackling the global issues that are typical of any social contract.

A social contract for science

Since the social contract we are considering now must regard specifically science (and technology as well), a careful analysis must be offered:

1. What are the indispensable specific characteristics of the subsystem 'science' that the contract must respect, promote and not compress?
2. What are the other social subsystems that are most directly related, via a network of feedback loops, with the scientific subsystem?
3. What are the non-social subsystems of the global environment that most significantly entertain feedback loops with the scientific system?

The consideration of (1) should clarify those performances, in terms of objective and reliable knowledge, that the scientific subsystem is specifically and uniquely capable of offering and that cannot be jeopardized in the social contract, since they are indispensable for the good functioning of the global social system and that of many other subsystems (the explicitness of such performances corresponds to the untouchable internal freedom of science).

The consideration of (2) should single out what outputs of the scientific subsystem could be valuable for other specific subsystems (e.g., industrial, economic, medical, military, welfare, transport and communication, political, moral, etc.), and also what inputs coming from the single subsystems could imply a fostering of the functioning of the scientific system.

The consideration of (3) should make clear what amount of environmental conditions are consumed by the functioning of the scientific system and what short-term, medium-term and long-term damages could be produced by this functioning. This analysis amounts to the indication not so much of prohibitions but of objective constraints that should be recognized for the functioning of the scientific system.

This analytic work, however, is only a first step and, as such, is still insufficient for the elaboration of a social contract, since it remains within a context of free competition that could easily imply that the scientific system operates chiefly at the service of those subsystems that offer it the most conspicuous advantages, disregarding the needs of other subsystems and even those of the global system. This bilateral approach (that remains limited even when it becomes multilateral) must be overcome by a genuinely global or synthetic approach.

The role of values

The transition to this approach is possible if the specific goals of each subsystem are considered as values in the sense that pursuing them is 'valuable' for the society as a whole. At this stage it is possible to see that the global system does not tend to the production of a particular kind of commodities or services but to the realization of a condition of 'good life' for all the members of the society. Such a condition of a good life or of a common good represents the global value for society, in which all the particular values are included, but in a balanced harmony that depends on a certain hierarchy of these values.

This hierarchy is not arbitrary, but reflects a humanistic approach in which the fundamental needs (material and spiritual) of human beings receive their adequate recognition. Using a terminology widely adopted nowadays, we could say that the social contract should reflect the preoccupation of respecting and fostering the wide spectrum of human rights.

Coming again to science, we can conclude that a social contract for science should essentially amount to outlining the ways of performing scientific and technological activities in full respect of human rights. These rights certainly include the freedom of research for pure and efficient knowledge, but also demand that such research not be self-referring. This means that the pursuit of the specific goals of science and technology must not be disjoint from the recognition and acceptance of several constraints that are represented by the presence of other, not less essential, values that both the present and future generations have the right to enjoy.

The social contract with science in developing countries

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The social contract with science in the next millennium in developing countries must consist of three concrete action points which will determine the spread of technology and the scientific temperament in the mass of people who will constitute over 80% of the world’s population.

First, institutions must be built up at the national and local levels with support from the international community so that those who help themselves in developing land, soils and water in the different agro-climatic regimes of the world get national and global support. Agenda 21 (United Nations Conference on Environment and Development, Rio de Janeiro, Brazil, 1992) and the ensuing discussion show that global sustainability problems such as sea warming and ozone-layer depletion can be solved only if local communities live in equilibrium with their resources. Biotechnology, modern trade and communication, new sources of energy, satellites and resource-mapping have all been used in successful examples of meeting the fuel, fodder and food requirements of the communities in the developing world in a sustainable manner. The social contract with science must disseminate incentives so that this happens on a larger scale and also enforce disincentives to discourage perverse people.

Second, it has been shown that the power of technologies like computerization, new materials, bio-technology and communication can be used in combination with small artisan and worker communities in the Third World to integrate with regional, national and global markets. New styles of organization are required, with support at the national and global levels, for accessing ever-changing technologies, quality control and standardization and promotion of flexible responses to market demands. These can be built around systems where local artisan communities take their own initiatives to link themselves with larger markets and higher levels of organizations. This part of the social contract will be necessary if technology and science are not to be seen as enclaves of ‘foreign domination’.

Third, science education and research have to be related to the basic needs of poor people in terms of primary health, literacy and education, access to drinking water, food and nutrition security; these need creative partnerships between local initiatives, more efficient organizations and distribution systems and public policy support at national and international levels of a much larger magnitude than seen today.

Finally, science and technology has to be seen as a handmaiden of peace cutting across cultures and bringing the peoples of the world together, rather than excluding and narrowing the human experience.

A need for capacity-building in Africa

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The importance of science in poverty alleviation, food security, supply of good-quality water, sound environmental management, good public health systems and industrial development is now well recognized.

What is not much known is that science promotes sustainable development if it is integrated with good governance: democracy, human rights and good environmental practices. Thus, if we consider the former Soviet Union, the former Eastern European countries and South Africa under apartheid, all three had a high level of scientific knowledge but, because of lack of good governance, they were unable to translate their scientific knowledge into socio-economic development of their people.

George Henrik Von Wright, a Finnish philosopher thus defines modernity as science and technology (S&T) on one hand and human rights and democracy on the other. Thus, mere national commitment to science is not sufficient for development. There are other factors.

In 1990, the literacy rate in Japan was 99%, in the Republic of Korea 96%, in the People's Republic of China 77% and in Malaysia 78.8%. Literacy rates in some African countries in 1990: Ghana 60.3%, Kenya 69%, Nigeria 50.7%, United Republic of Tanzania 43%, Democratic Republic of Congo 38.2%, Burkina Faso 18%, Togo 43%.

These low literacy rates in sub-Saharan Africa explain the poor agricultural and industrial productivity and low life expectancy, which is about 50 years and below, compared with that for developed countries of 73 years and above. Thus, utilizing science, less than 3.5% of people in the advanced countries are engaged in agriculture to produce sufficient food for their people. In Africa, because of lack of scientific awareness, over 65% are engaged in agriculture and yet cannot produce enough food for people.

According to the report of the United Nations Children's Fund (UNICEF), there is a strong correlation between education and mortality rates, especially child mortality. A 10% increase in girls' primary school enrolment can be expected to decrease infant mortality by 4.1 deaths per 1 000 and a similar rise in girls' secondary school enrolment could slash mortality among infants by another 5.6 deaths per 1 000. The report estimated that in Pakistan an extra year of schooling for an additional 1 000 girls would prevent 60 infant deaths.

In his speech to the Third World Academy of Sciences' 1997 General Conference in Rio de Janiero[1], Professor José I. Vargas, President of the Academy and former Minister of Science and Technology of Brazil, remarked that the increase in Brazilian gross national product (GNP) by a factor of 12.5 from 1947 to 1988 was due mainly to educational expansion, particularly that of university education.

From what we have said so far, it appears that in Africa the major problems which need to be overcome are to increase the literacy rate and to build a strong capacity in science at the various levels of African civil society.

A commitment to increasing the level of literacy and numeracy must be a prime requirement for all nations. To this end, African nations:

- must establish, through their national educational policies, strong links between stakeholders in their education system to ensure curriculum development across the full educational process, giving attention to the need for coordination at every stage of a student's development;
- should seek more sponsorship or assistance from international agencies and from the private sector, recognizing Africa's inadequate local resources, to help narrow the gap between Africa's education system and that of the developed world;
- must raise the level of awareness of the value of S&T among the general population and among those who influence educational policies.

Any capacity-building programme in S&T in Africa must have the following objectives:

- increase participation of disadvantaged groups in S&T, such as youth and women;
- promote regional and international cooperation in research and training;
- stimulate growth of the utilization of newer and emerging technologies;
- encourage the establishment of S&T funds for national and regional programmes;
- ensure free movement of scientists;
- promote investment in human resources development including training for the sustainable management of S&T equipment.

In this context, strong and concerted international support is needed to build up the scientific community and scientific infrastructures of Africa. In fact, scientific excellence and integrity need to be combined with a close dialogue and cooperation with policy-makers and implementers including full participation by experts with local knowledge in Africa. It is important to strengthen the cooperation between local and external experts to ensure full understanding of socio-economic, cultural and ecological problems.

Infrastructure and telecommunications

In order to effectively attain an operational capacity in S&T, it is a necessary prerequisite that adequate infrastructure be established in information technology, in particular through national telecommunications policies, to enable African researchers and educationalists to optimally utilize their resources. Thus, scientists in Africa must be able to:

- access information databases;
- establish electronic networking for dissemination of S&T information;
- develop a virtual university in all subjects, but in particular in S&T, which will link African universities and centres of excellence.

Academic exchange programmes

- Exchange of experts/scientists, collaborative training for research and development (R&D) programmes, access of African scientists to international facilities, intra- and extra-African student, postdoctoral and faculty exchanges, active participation of African scientists in international S&T bodies, establishment of regional centres of excellence.
- University-industry links: internships' joint research programmes, sandwich degree programmes, sharing of laboratory facilities/infrastructure; multinational corporations in Africa should invest in R&D programmes in Africa.

I shall conclude my paper by citing some concrete initiatives in capacity-building in Africa through international cooperation. In the areas of physical and mathematical sciences, a lot is being achieved by the Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste, Italy, in capacity-building and in R&D in Africa. Applications of lasers cover very diverse fields such as medicine, agriculture, optical communications, conservation of the environment, industry. With this in mind, ICTP has established in Africa a Laser, Atomic, Molecular and Optical Sciences (LAM) network at some African universities and research institutions.

The main objectives defined for the LAM network are the following:

- to promote the development of the physics and fundamental research on lasers, atoms, molecules, optical sciences;
- to extend the field of applications of these for the benefit of economic development in Africa.

The network currently has sites in 36 African universities from Egypt to South Africa. Since its inception in 1991, it has organized five international and regional workshops and conferences in Africa and it has a close relationship with the International Commission of Optics. It has five centres of excellence. These centres run MSc and PhD programmes in laser and optical sciences.

The World Bank has initiated a virtual university programme, known as the Africa Virtual University, at 12 selected sites in universities of six English-speaking countries in Africa: Ethiopia, Ghana, Kenya, Tanzania, Uganda and Zimbabwe.

The Society of African Physicists and Mathematicians (SAPAM) was founded in 1983. Since its founding, it has organized 36 regional and international conferences, seminars and workshops in 10 African countries. Among its objectives are:

- to promote and further education and research in physics and mathematics and their applications to enhance technological, economic, social and cultural development in Africa;
- to promote effective contacts and cooperation among African physicists and mathematicians;
- to collaborate with international organizations in further scientific activities in Africa.

Sandwich PhD programme

A number of Africans have been sent to advanced countries for PhD programmes. The return rate is minimal. They were easily absorbed by educational and research institutions in these countries. According to a 1995 UNESCO report, about 30 000 African PhD holders are working in the developed countries. To overcome this, with the assistance of the ICTP and Third World Academy of Sciences (TWAS), a Sandwich PhD programme has been launched in selected African universities, particularly in the areas of mathematics and physics where the problem is very acute. It should be mentioned that, faced with a similar staff problem, Philippine universities mounted a Sandwich PhD programme with help from the Governments of Germany, Japan and Australia; within the past 21 years of its existence, the programme has been able to produce 45 PhDs.

The concept underlying the implementation of the programme is that PhD students take academic courses in the universities in Africa, using visiting scholar and visiting professorship programmes of ICTP/TWAS to lecture in these universities through North-South and South-South collaboration:

- students go to a university abroad to start thesis research with a foreign adviser;
- students return home to complete their thesis with a local adviser;
- students receive a PhD from a local university.

In conclusion, S&T is necessary but not sufficient for development; there is also a need for good governance. To develop science in Africa, there is a need for a good basic education, capacity-building and international cooperation.

Note

1. The TWAS General Conference in Rio de Janeiro, Brazil was associated with the World Conference on Science. The meeting report can be accessed at the following address: http://www.unesco.org/science/wcs/meetings/lac_rio_de_janeiro_97.htm

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Access to healthy water and an efficient wastewater treatment system

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The legacy of the 19th century for the oldest industrialized countries was a heavy burden of pollution. The 20th century will leave a much greater understanding of environmental problems, along with well-proven technologies and institutions. However, our century is also leaving future generations many untreated problems that have been ‘stored’ in the natural environment or special facilities – toxic waste that has been inadequately eliminated, if at all; chemical pollution from pesticides, nitrates and so on in the soil, sediment and water tables; as well as outdated plant and water systems, and deserted agricultural, industrial and urban sites.

While the priority to date has been to treat ‘flows’ (pollution emission and resource sampling), the 21st century will have to pay more attention to managing and restoring ‘stocks’. This focus on the problems of stocks, capital and assets is, to some extent, central to the notion of sustainable development.

Environmental pressures will increase in the next 30 years, particularly in southern countries, where there is huge growth in major urban centres: 60% of all cities with more than 5 million inhabitants will be in the Southern Hemisphere.

Water is a major strategic priority for the economic development of these large cities. The doubling of the urban population in southern countries – 2 billion now, 4 billion in 2030 – and the concentration of people in large cities will have enormous consequences for the management of water resources and pollution levels. It is now estimated that 28 countries with a combined population of 338 million are suffering from water shortage. In other words, they have less than 1 000m^3 of renewable water resources per year per person. By 2025, there will be 46-52 countries, representing 3 billion people, in the same situation.

The social and ecological cost of this metropolitanization is growing and can no longer be ignored. Poverty, the lack of infrastructure, poor-quality housing and overpopulation are the typical characteristics of suburban sprawl. Against this backdrop, supplying drinking water to a local authority – and supplying it to everyone – is still the constant practice of water companies, which sometimes come up against the huge scope of the social difficulties in the new metropolises.

The water industry has a responsibility to society, which is why it wants to take up this challenge. But it can only do so in conjunction with other public and private entities. That is the purpose of the work started by the World Bank through an informal network of companies, civil society organizations (non-governmental organizations (NGOs) and social welfare organizations) and government ministries. The Business Partnership for Development (BPD) programme, as it is known, is based on the premise that partnerships between these three sectors offer strong added-value.

The industrial partners participating in this programme are Générale des Eaux – Vivendi, Suez-Lyonnaise des Eaux, Thames Water, Aguas Argentinas, Aguas de Barcelona, Aguas de Cartagena, Aguas de Illimani, Northumbrian Water and Hydro-Conseil. The non-commercial partners are CAMEP (the national water company of Haiti), local governments, city planning and local public works authorities, UMGENI Water, universities and NGOs such as GRET, Lembaga Swadaya, Masyarakat, Myula Trust and the programme ‘Solidarité Eau’.

BPD is organized jointly by the World Bank, Générale des Eaux and Water Aid. The partners have identified projects in various metropolises in the world where sector-based partnerships play an important role, working together and sharing their experiences in order to find solutions for the city of the 21st century. To date, seven projects have started, one in each of Argentina, Bolivia, Colombia, Haiti and Indonesia, and two in South Africa.

All the partners share the philosophy that all users must be supplied with water that will protect them from any health risk. To go down that track, it is not enough to export technology. It is only by working with researchers in the different countries in which we operate that we will find concrete solutions appropriate to the local context.

In emerging markets, we have to develop new financial and technological approaches in order to meet our growth targets and satisfy the demands of sustainable development. The challenges we face are therefore just as much economic and social as they are technical. To invest in heavy infrastructure, which is often without market value, the water utilities must be able to cover certain risks. One such risk is the ability of users to pay for their water.

The current trend is towards more urban sprawl, resulting unfortunately in greater inequalities and the creation of poor, rundown neighbourhoods, which lead to frustration and revolt. The management of water services in such areas calls for a review of the way the services are organized, with active participation by the local communities and the provision of different levels of services accepted and supported by the local communities and institutions.

About 1.7 billion people – more than one-quarter of the world’s population – do not have direct access to drinking water, and the poor quality of water causes 25 000 deaths a year. The lack of wastewater and industrial waste treatment facilities is mainly to blame for the high levels of contaminated drinking water. The needs for capital expenditure are huge and exceed by far what public funding bodies can afford. The private sector is therefore asked to make up the difference, but we are reaching the limit there, too. The city of tomorrow has to be reinvented to make way for a more intelligent use of resources.

Lastly, there is a need to develop techniques for industrial water treatment and recycling. The sustainable cities of tomorrow will benefit from the emergence of an ‘industrial ecology’ in which production and recycling take place systematically in closed circuits. This should lead to a very significant reduction in the impact on the environment. This new trend is opening up promising prospects for our industrial customer business.

Most of the treatment, pollution emission reduction and recycling techniques are developed in industrialized countries, because they have greater technical and financial resources. The main challenge is to transfer these technologies to emerging markets, where large-scale implementation will probably become urgent in a period of high growth in facilities, manufacturing industries and capital goods. Companies operating worldwide, like Vivendi, have the capacity to spread and accelerate the distribution of these technologies.

Tension also exists in industrialized countries, which are confronted increasingly by a deep uncertainty, that of the ‘risk society’. The evolution in information technology is transforming our observation and knowledge systems. Technical progress in other fields also gives rise to a new generation of risks and uncertainty. Utilities companies are confronted by these realities all the time – people worry about the quality of the air they breathe, the water they drink and the disruptive nature of the noise around them.

We have to cope with the impossibility of being able to measure, or even anticipate, the full impact that the evolution of technical systems will have on nature and human health. The French legal definition of the principle of prudence (Law 95-101 on strengthening environmental protection) is worth noting here. It is the principle ‘according to which the absence of certainty, based on available scientific and technical knowledge, must not delay the adoption of effective and proportionate measures aimed at preventing a risk of serious and irreversible damage to the environment at an economically acceptable cost’.

A constant dialogue between scientists, industry and civil society representatives is needed. However, there remains one burning question: who is in a position to define the ‘economically acceptable cost’?

Prospects for science in Latin American countries

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General situation in Latin America

The 1980s are known as the lost decade for Latin America from the macro-economic point of view because of the burden of the external debt, heritage of the 1970s. After that, the 1990s showed stabilization and economic growth. So, compared to a decrease of 1% in gross national product (GNP) per capita between 1981 and 1990, there was an increase of almost 2% between 1991 and 1998. This growth allowed a slight reduction in the percentage of the population below the poverty line from 41% in 1990 to 36% in 1997. This, however, means an increase in the absolute number of Latin American poor from 200 million to 204 million. Moreover, the growth of GNP is not parallelled by the solution of social problems as shown, for example, by Argentina, where an increase of 37% in income per capita was accompanied by only a 3% decrease in the percentage of the poor.

A social distortion in Latin America is the high concentration of income. The gap between upper and lower classes is rising. An indicator is that the remuneration for qualified work has increased by more than 40% as compared to non-qualified work. And unemployment in many cases has increased, as in Argentina where it reached 15% in 1997.

Due to the financial crisis in different parts of the world, economic activity in Latin America is declining. So, in 1998, growth in GNP per capita was only 0.7%, compared to 3.5% in 1997. The outlook for 1999 is for deepening recession, because of the Brazilian financial crisis and the low prices for export products. The latter originated a negative trade balance that increases the deficit in the current account, which already reached –4% in 1998.

The decline in economic activity has increased average unemployment, which climbed to 8% in 1998 with a much higher index of 20% in the industrial region of Brazil. The exception is Mexico, due to the good performance of the US economy, which is its partner in the North American Free Trade Agreement (NAFTA), where unemployment decreased to below 5%. The fiscal deficit is forcing severe cuts in social expenses in all the major countries of Latin America, including those devoted to education and scientific research. This intrinsic macro-economic weakness of Latin America is due to the small amount of production of manufactured goods based on advanced technology.

University and research

In Latin America, there are three countries – Argentina, Brazil and Mexico – with a longer tradition of scientific research in their universities and national laboratories. As an example, the first society of physics in the region was the Asociación Física Argentina, founded in 1944 to organize meetings for presentation and discussion of original works, having arrived that year at the 84th national congress. In the early years, postgraduate studies were pursued abroad, but already in the 1950s PhD students began to study in these countries. Again, as an example, in 1959 three eminent scientists, J.J. Giambiagi from Argentina, J. Leite Lopes from Brazil and M. Moshinsky from Mexico, started the Escuela Latinoamericana de Física rotating in different countries to update young physicists on new discoveries; it inspired the founding of the Centro Latinoamericano de Física in 1962 with the purpose of stimulating research and postgraduate studies through regional collaboration.

Certainly, the breaking down of democratic institutions frequent in the 1960s and 1970s negatively affected scientific development, but on the whole these three countries have a well-established postgraduate system, mainly based on the public universities, with a certain number of fellowships for Latin American PhD students.

Another group of countries has reached more recent scientific development: Chile, with a rather small but highly qualified scientific community; Colombia, which is perhaps the country with the fastest development in recent years; Venezuela, handicapped by the depreciation of oil, which is its basic natural resource; Cuba, with a comparatively large number of scientists but an extreme lack of funds. Costa Rica and Uruguay are among the socially best-balanced countries in the region and have universities of a good standard, but are too small to perform autonomous research. All these countries are in a position to produce their own PhDs either individually or in collaboration.

The rest of the countries require much international support. Among them, Peru is emerging due both to the number of students doing their postgraduate studies abroad and some local initiatives.

On the whole, the resources devoted to research and development (R&D) are well below the 1% of GNP which seems to be the limit below which there is no development. In general, linkages with industry are very weak, partly due to private factories not being interested in conducting research in Latin America and partly due to a tendency of some scientists to become isolated in their academic activities. An exception is Brazil where several links have been established with benefits for both industrial production and for the fulfilment of scientific enterprises' undertakings.

Conceptual changes in values

The present framework of globalization in the world is based on considering money as a supreme value. This leads to a flood of financial capital, which goes almost instantaneously from one country to the other according to their immediate benefit. These changes, possible due to fast electronic telecommunications and lack of regulations, may produce a crisis in the emerging economies, i.e. in the weaker part of the globalized international system.

The sudden crisis in one country is not easily understood by its citizens, who hesitate between blaming their government or supporting it, eroding the basis of democracy which requires knowledge of the responsibilities of rulers in order to vote consciously. Even though frequent instability might produce a general collapse and consequent depression, it is more likely that it will affect those countries which do not have a genuine and strong economy based on competitive production and which are therefore easy objects of speculation.

For all humankind it is imperative to become convinced that other values apart from immediate profit must be accepted. The consideration that the harmonious development of societies is in the end better for everybody should suggest regulations governing the movement of capital and the need to contribute to social expenses.

Many people are disappointed because they believed that science would solve all problems in a linear way. This has been proved not to be true because other decisions must be taken apart from that to support science. But, even if not sufficient, science is certainly necessary for progress. It suffices to look around and see the ingredients of modern life to realize that most of them were made possible by scientific discoveries at the beginning of the 20th century which at that moment could hardly be considered as useful for application to common needs. And, last but not least, scientific knowledge indicates the arrow of time and has the intrinsic value of being one of the best conquests our species has made.

Suggested steps in Latin America

Even though the linear model that basic research automatically leads to applied science which originates technology is simplistic, it is true that some basic science must be done in every country. Apart from the fact that a genius may appear anywhere, the standards of pure science are useful to judge the merits of any applied enterprise.

Therefore, states should increase support to research in an equilibrated way between basic and applied science. Universities, and national laboratories linked to them, are the natural places for doing research in Latin America because, due to the necessarily not too large number of scientists, the presence of advanced students will contribute much to the success of the work.

On the other hand, scientists must submit reports of their work in order to evaluate the originality of basic research and the usefulness of applied research. Again, because of the not too large number of scientists involved, it will be convenient to avoid dispersion into too many fields of research, which would lead to isolation and would decrease the possibility of success.

The situation of public universities deserves special consideration; they are in serious budgetary difficulties even in the three major Latin American countries. There is a tendency to restrict admission and require the payment of fees by students. Both roads are dangerous. Due to the social inequalities in Latin America, the preparation obtained by students at high schools is of very varied quality. Therefore, the admission exam may produce results which are not related to the intellectual qualities of the applicants. It is much better if universities orient students towards those careers more suited to their specific conditions and required by social needs, which may facilitate their finding a job subsequently.

Also, the payment of a fee by students, which is usually suggested on the condition that those with low financial possibilities obtain a waiver, is impractical for unequal societies where the entire procedure would be very complicated with the only result being a reduction in the number of students, who would be discouraged by the economic difficulties. A more convenient system would be a legal commitment on the part of students by which they will pay back the university after the completion of their studies in proportion to the salaries they obtain.

Contacts between university and industry should be favoured. This is certainly a delicate matter because one should ensure that the emerging possibilities of technological innovation are open to contracts with all interested external actors, on the one hand, and that the financial benefit obtained by the researchers is distributed equitably as additional resources of the university, on the other hand.

It seems to be of the utmost importance to establish a network of Latin American institutions for postgraduate studies with the corresponding fellowship system. There are several countries in the region that can offer supervision of PhD work, sometimes alone or in collaboration with other institutions. For those countries that are not yet in a position to organize postgraduate studies, intergovernmental organizations and other international institutions should, on the one hand, select young students to pursue their PhD career abroad and, on the other, stimulate research activities in the country of origin of these students, which may lead as soon as possible to the required level of expertise. A programme of this kind is being supported by the Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste, Italy.

Regarding research projects, these are often beyond the possibility of a single country. This has been seen clearly by European scientists who have very successfully promoted joint research centres. Something equivalent has not happened so far in Latin America and it is urgent that collaboration in mega-projects and the common use of experimental facilities currently existing in national laboratories be established.

Again, to reach this goal, agreements among the major countries with active research groups should be signed and the participation of scientists of the comparatively less developed countries should be stimulated by intergovernmental organizations. Examples within the framework of broader international collaborations in research on cosmic rays are the Auger observatory in Argentina and new experiments at the historical laboratory of Chacaltaya in Bolivia, together with the possible Latin American use for materials science and medical applications of the existing synchrotron light facility in Brazil and the projected laboratory in Cuba for the microtron accelerator built at the Joint Institute for Nuclear Research (JINR) in Dubna, Russian Federation.

The same goes for scientific journals. It is time to join hands in publishing in the region at a recognized international level. Many national journals exhibit the merit of having promoted science in the past. But now, only by uniting as Latin American journals may they ensure the resources, timing and specialized editorial staff to reach the quality and diffusion of the publications in other regions of the world. As for collaboration in research, the almost common language should be favoured in agreements.

A last word must be said regarding the bureaucratic obstacles still existent in Latin America in several countries for the exchange of students. In an age when citizens of the European Union travel from one country to the other without control of documents, in Latin America the usual rule is to ask for visas which often require months to obtain and expenses that cannot be afforded by students. These difficulties have no possible justification for students who have been accepted by institutions in another country of the region. Since the financial contribution that is necessary is so meagre on a state scale, one might expect that these obstacles to free mobility could be quickly removed.

The end of the 20th century appears hard for the periphery of our globalized world. But the evolution of history is not deterministic and the efforts of scientists may contribute to a more harmonious development of society in the 21st century.

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Dubna: an island of stability

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The role of science in society

I would like to share some considerations on the role of fundamental science in the context of a new social contract using the example of the Joint Institute for Nuclear Research (JINR). Unfortunately, the attention of society to fundamental science has been waning in the modern world for many reasons. But it is well known that achievements in fundamental science determine the level of modern civilization: the intellectual and moral climate, educational level, possible development and, lastly, flourishing of society. The role of fundamental science was estimated in one sentence by a well-known American physicist, Richard Feynman, who said that 'Maxwell's equations are of more importance for mankind than the French Revolution'.

Hard times for science in Russia and the CIS

What is the current situation with science in Russia and the Commonwealth of Independent States (CIS)? It is absolutely clear that fundamental science has been experiencing extremely hard economic conditions in these countries because of the newborn market economy, which has resulted in a noticeable reduction in state financing for fundamental science. At the same time, new mechanisms typical of the market relationship have not yet been developed over such a short period of time to support science in the former Union of Soviet Socialist Republics (USSR).That is why it is necessary to work out objective criteria and principles governing the selection of the scientific directions which should be supported by the state financially and politically in the new conditions.

Possible state criteria to support science

What criteria may be taken when choosing the priority scientific directions supported by the state in Russia now? As experience has shown, the highest priority criterion for state support of fundamental science is wide, effective integration of Russian science and research institutions into international collaborations and large international projects. The international usage of unique Russian scientific machines is also of great importance. Only this reasonable combination in cooperation would help to preserve and develop scientific-technical potential in the former Soviet Union and involve young scientists in prospective research.

So, if one is to propose directions in fundamental science that should be supported by the state, these should meet the following requirements of society:

- be world-recognized because of their contribution to scientific achievements;
- have formed scientific traditions and schools;
- have a high rating at present.

Besides, they should be attractive for non-budgetary sources of financing. And lastly, the most important feature of fundamental investigations and a guarantee of their openness, in our opinion, should be their international character. In other words, fundamental science should make efforts to be visible and acceptable by society in a new socio-economic context.

International character – a factor of stability: the example of JINR

From the other point of view, the role of international research centres, collaboration and cooperation in general is increasing at present. In this connection, I would like to give a positive example of the JINR in Dubna[1]. Located in the territory of Russia and uniting 18 member states from the Eastern Region, half of these countries being former Soviet republics, this centre is successfully withstanding the financial and economic crisis in Russia and the countries of the former Soviet Union.

The JINR, being a huge cementing force, has succeeded in preserving the common intellectual space in which scientists of the former USSR used to work. One of the key factors for achieving stability of the JINR is its international character. The experience of the JINR could, in our opinion, be not only studied but also expanded into other fields of science.

The JINR was founded in 1956 to unite efforts of the member states in research on fundamental properties of matter, strictly following the principle of wide-scale cooperation not only with its member states but also with many other countries of the world.

Box 1 shows the structure, main fields of activity, both in fundamental and applied research, required by society, and basic facilities of the JINR which is now an efficient bridge between East and West, promoting stabilization of the political situation in the modern world. Established traditions of scientific schools, a high level of research and its unique scientific basis attract scientists from different countries to this centre of fundamental research.

On the basis of the JINR, international cooperation is alive and well. The discovery of the element 114 and the island of stability has proved it once again. I mean the experimental discovery of a super-heavy element with atomic number 114 and mass 289. In late December 1998, a group of scientists from the JINR Flerov Laboratory of Nuclear Reactions, in collaboration with colleagues from the Lawrence Livermore National Laboratory (USA), synthesized a new long-lived (30s) super-heavy element of the Periodic Table with atomic number 114. This discovery has crowned 35 years of efforts by physicists from the JINR, USA and Germany in search of a stability island for super-heavy elements.

Sponsor funds

During the intermediate period of establishing the market economy, one of the tools to stabilize the situation in fundamental science is international funds, which, together with the support of science in Russia and the former Soviet Union, are intended to prevent ‘brain drain’ to other countries, promote conversion of military science and preserve cooperation traditions between laboratories of the West and the East. In particular, I would like to stress the activity of INTAS (International Association of Academies of Science) in promoting cooperation with scientists from the CIS, and of ISTC (International Science and Technology Centre). These two international funding agencies were set up and became active in 1993. Both agencies chose the bottom-up approach, supporting research projects in East-West collaboration. It should be noted that INTAS plays an important role in preserving the joint intellectual space for our scientists. This

Box 1. **Joint Institute for Nuclear Research (Dubna, Russian Federation)**

Main fields of activity

Theoretical physics
Elementary particle physics
Relativistic nuclear physics
Heavy ion physics
Low and intermediate energy physics
Nuclear physics with neutrons
Condensed matter physics
Radiation and radiobiological research
Networking and computing

General information

The Joint Institute for Nuclear Research is an international intergovernmental scientific research organization established in 1956, the activities of which are based on the principles of openness to participation by all interested states and equal, mutually beneficial collaboration.

The JINR Member States are:
Armenia
Azerbaijan
Belarus
Bulgaria
Cuba
Czech Republic
Georgia
Kazakhstan
DPR Korea
Moldova
Mongolia
Poland
Romania
Russian Federation
Slovak Republic
Ukraine
Uzbekistan
Viet Nam

Many scientists and engineers from the Member States were trained in the JINR scientific schools established by outstanding physicists including:
N.N. Bogoliubov
D.I. Blokhintsev
G.N. Flerov
I.M. Frank
B.M. Pontecorvo
V.I. Veksler

The development of different scientific directions at JINR is connected with the names, among others, of
L. Infeld and
G. Niewodniczanski (Poland)
G. Nadjakov (Bulgaria)
H. Hulubei (Romania)
L. Janossy (Hungary)
N.Sodnom (Mongolia)
Wang Gang Chuan (China)
Nguyen Van Hieu (Viet Nam)
V. Votruba and Ya. Kozesnik
(Czechoslovakia)
H. Pose and K. Lanius
(Germany)

Annually about 50 national and international workshops and conferences are held at JINR.

The Committee of Plenipotentiaries of the JINR Member States is the highest body of the Institute. The scientific policy of the Institute is formed by the JINR Scientific Council and the immediate control over the Institute activity is exercised by its Directorate.

Directorate

Director: V.G. Kadyshevsky
Vice-Director: A.N. Sissakian
Vice-Director: Ts. Vylov

Laboratories

Bogoliubov Laboratory of Theoretical Physics
Laboratory of High Energies
Laboratory of Particle Physics
Laboratory of Nuclear Problems
Flerov Laboratory of Nuclear Reactions
Frank Laboratory of Neutron Physics
Laboratory of Computing Techniques and Automation

Accelerators and reactors

Nuclotron: Superconducting synchrotron for nuclei and heavy ions up to 6GeV/n
Synchrophasotron: 10GeV proton and light nuclei accelerator
U-400, U-400M and U-200: Heavy ion cyclotrons
IBR-2: Pulsed reactor with neutron flux 10^{16}n/cm^{2}s
IBR-30: Neutron pulsed booster multiplier
Phasotron: 680MeV proton accelerator
IREN: Intense resonance neutron source (under construction)

Educational programme

The JINR University Centre (UC) was founded in 1991.

Students of senior courses from the leading Moscow educational institutes and JINR Member States complete their studies and training at the Institute's laboratories and UC in the following fields: high energy physics, nuclear physics, nuclear methods in condensed matter physics, technical physics and radiobiology.

In 1995 postgraduate studies were added to the educational programme of the University Centre.

association emphasized at a Minsk workshop held on 14 January 1999 that full-scale integration will become possible only if scientists from the countries of the East participate in international scientific programmes and projects and this participation does not depend on non-scientific criteria. It seems to me that it is the role of UNESCO and other international bodies to support this tendency.

CERN-JINR cooperation

As a concrete example of this collaboration, I would like to mention the cooperation between the JINR in Dubna and the European Laboratory for Particle Physics (CERN), bringing nations together for more than four decades. It is remarkable that CERN and JINR for the last three years have been nominated for the Nobel Peace Prize, since they are known not only for their achievements in the field of fundamental science but also for their important contribution to mutual understanding between peoples on our planet. This cooperation was reflected in the photographic exhibition, 'Science bringing nations together', prepared jointly by CERN and JINR. It was held in UNESCO in Paris, France, in October 1998. In early May 1999, the presentation of this exhibition took place in the Palace of Nations at the Geneva office of the United Nations. Nowadays, in such an uneasy world when the importance of fundamental science is, unfortunately, diminishing in public opinion from year to year, these exhibitions are needed for peoples and governments to correctly estimate the eternal value of this field of human activity.

Conclusion

Thus, we realize that the modern world without integrated fundamental science is beyond imagination. In the meantime, fundamental science as a global phenomenon has not been studied seriously and deeply enough, not yet. The problem of intellectual property in fundamental science, the economic efficiency of fundamental research and a set of other issues are expected to be considered in the future.

As for the JINR, very often scientists and politicians from different countries ask the question: 'How does this research centre manage not only to survive but to obtain important scientific results in such a hard economic situation in the former Soviet Union?' The answer is simple; the JINR in Dubna always tries to stick to the criteria mentioned above. Probably, its example and experience would be especially useful for centres of the East, not only to study but also to expand into different fields of science.

The JINR, which is called 'the island of stability' in easy reporters' language, will celebrate its 50th anniversary early in the 21st century. We hope to enjoy this jubilee with new scientific achievements and in a situation where society adequately estimates the great advantages of fundamental science for the sake of people.

So, my conclusion can be reduced to the following statements:

- Fundamental science should make efforts to be visible and acceptable to society in the new socio-economic context.
- The international character of fundamental science is the most important criterion in choosing the directions to be supported by the state.
- The positive experience of the JINR in Dubna could be useful for other research centres to expand into different fields of science.

In accordance with the recommendations of the Minsk workshop[2], I would propose including the following sentence in the *Declaration on Science and the Use of Scientific Knowledge* to be adopted by the World Conference on Science: 'In order to get the maximum use of all available intellectual potential of the planet for overcoming the global civilization crisis, [the participants] consider necessary a broader integration of scientific organizations from developing countries and countries having a transitional economy into major international scientific centres, programmes and projects.'

Notes

1. The JINR page can be accessed at http://www.jinr.dubna.su/ for detailed information.
2. Universal Value of Fundamental Science. Science is outside of Boundaries. Meeting of National Academies of Sciences and scientific funds of countries of CIS and Eastern Europe, Minsk (Belarus), 14 January 1999. The message from this meeting associated with the World Conference on Science may be accessed at the following address: http://www.unesco.org/science/wcs/meetings/eur_minsk_99.htm

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Building a new social contract

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During the period of the Cold War, the model of science and basic research established by V. Bush, the US Presidential Science Adviser (1945) was widely accepted. According to this model, governments put money into basic research, out of which will result, at some time or other, contributions to wealth, health and national security. This was the so-called 'social contract for science'. Such a postulate about the social benefits of science was, moreover, combined with the argument that the market cannot guarantee an optimal allocation of resources to research. This set of arguments opened a large avenue for the public funding of science. This era is now past. All developments identified and discussed above undercut the traditional public good economic rationale for the public support of science. Scientific knowledge becomes, in many cases, a private good. The 'close to market' rationale is used to select areas for scientific explorations according to their commercial relevance. All those evolutions can have perverse effects.

There is, thus, a need to construct a new social contract – taking into consideration the key features of the scientific enterprise (openness, long-term research, equity issues), while recognizing the importance of increasing collaboration with industry, as well as the need for joint research agendas between the natural and social sciences, acting as equal partners (the interaction between the natural sciences and technology and society cannot be optimized unless social sciences participate in the game, on their own terms, with adequate resources). Such a social contract also needs to specify certain new targets (to take precedence over the objective of reinforcing military power).

A new target

In a path-breaking paper, J. Lubchenco (1998) speaks for the building of a new social contract for science oriented towards the production of scientific knowledge to understand and manage the biosphere. Arguments she provides about the consequences of human domination of Earth are so convincing that no one could dispute the point made in that paper: we need more science (and technology) in a broad spectrum of areas as well as through interdisciplinary research, to cope with most of the environmental challenges of the new century. It is, however, important to note that the environment should not be taken as the only issue for the new social contract but that development also matters. This is important to consider, because most of the policy discussions in international forums increase the perception of at least one example of tension between the environmental challenge and the development issue; environmental challenges are often perceived as an obsession for rich countries, whereas the hope of developing countries is to struggle against poverty. Now, the point is that science and technology are unique in offering the possibility to reconcile and make compatible the need for environmental strategies and the need for economic development in the global world. Here is a real social contract for science: managing in an integrative manner both issues, avoiding that environmental objectives can be detrimental to economic development. In other words, socio-economic sustainability should be considered on an equal footing with environmental sustainability. In these issues, the unsustainable consumption patterns of the North is a central point to be tackled.

Preserving the basic principles of knowledge openness and research for the long term

On openness

It is important to recognize that a major part of basic scientific research is carried out under an open principle – new knowledge is disseminated largely and quickly. Distributing scientific information is one means of increasing the efficiency of scientific investigation, since it can serve to reduce duplicative or wasteful lines of research and to increase the probability of new fruitful combinations of ideas and projects. Economists explain that this principle of open science provides private incentives to generate public goods and has demonstrated its effectiveness as an incentive system. Thus, standards of conduct regarding disclosure and investigation of the efficacy of the distribution of knowledge become the first priority in attempting to assure that public expenditures on science generate value for the tax payer (David *et al.*, 1997).

But the new context, where proprietary science and intensive privatization of knowledge clash directly with the conditions for knowledge dissemination and access, makes it very difficult to meet such a challenge.

On long-term research

We are living in an economic world in which 'the present value of future benefits is very low'. Real rates of interest have been at historically high levels since the early 1990s, reflecting a social preference for current consumption instead of investment for the future. Science, like other activities oriented towards long-term achievements has, thus, difficulty in getting a large basis for investment.

In such a context (in which the present value of future benefits is very low), the use of cost-benefit (c/b) analysis cannot provide a relevant basis for decision-making (Steinmueller, 1995): because long-term benefits are worth little to the present generation, there is little basis for investment. C/b analysis is, therefore, highly opportunistic, since past generations cannot revoke their bequests and future generations cannot protest against our failure to provide for their welfare.

There is, thus, a need for new approaches such as that based on inter-generational equity: future generations have the right to demand a knowledge legacy, as we currently benefit from knowledge produced by past generations. It is well known that the market is not the appropriate institution for solving such questions and that it is a responsibility of the public institutions to facilitate this inter-generational and inter-spatial distribution of resources.

The need for new governance structures

The global science system has been strained by the rising costs of maintaining the capability to do basic science, which have pressed against tightening national budgets. Given this trend as well as the new context of slower growth of public budgets, and given the inherent limitations of industry funding and charity mechanisms, there is an urgent need for generating new mechanisms for funding science and in more general terms for implementing more effective governance structures.

The issue of improving international coordination and cooperation must be considered here. This is particularly important in the case of certain kinds of research requiring large facilities (experimental research in the field of high-energy particle physics) or large programmes (Human Genome Project). The size of certain large facilities has made it simply unfeasible for many nations to maintain research activity or to sensibly run university training for their own graduate students in a growing number of fields – except by entering into cooperative arrangements for the construction and operation of large scientific facilities.

In fact, there is much less basic research and big science collaboration than might be expected given the presumed benefits of and incentives for cooperation, though there is substantial and growing international collaboration among industrial firms. International cooperation requiring substantial and/or reliable funding has not grown in scale commensurate with the increasing costs of research, the international nature of emerging science and technology-rich issues, the spread of scientific competence or the growing ease of communications.

International coordination must involve developing countries. Until now, scientific priorities were never decided through international coordination and major conflicts on the final use of the products of science occurred. The time is past when developing countries were content with financial compensation. They now request to contribute to the writing of the rules!

Science and democracy

The opportunities for constructive change in the global scientific community appear to be very large, despite growing financial pressures and some diminution of the public commitment to the scientific enterprise. The growth of international cooperative arrangements in science and the increasing use of information and communication technologies will increase linkages within research networks and reduce the distance between researchers. There seems little doubt that this process will lead to a growing interest in reforms aimed at increasing the integration of resource allocation, research planning and scientific information distribution. Perhaps the most significant international challenge is improvement in the global cohesion of the scientific community, in assuring that the division of labour among researchers reflects their ability to contribute to the scientific enterprise rather than the wealth or dominance of their country relative to others. The aim of policies in this area should, in the first instance, be to avoid increasing the disparities and disadvantages that are already present. In the second instance, the aim is to develop realistic and practical policies for lessening disadvantages, particularly where these disadvantages interfere with the transmission and use of scientific information. These issues are particularly significant for the economies in transition, for smaller countries and for the industrializing countries.

Important policy issues deal with the questions: How can we broaden access and participation of researchers from countries that are outside the main coalitions of scientific power? What methods can be adopted to improve the international distribution of scientific information and reduce the barriers to the participation of researchers in global scientific networks? A dilemma in this area is the policy of making major scientific equipment and research programmes available to scientists from countries which do not help to pay for such resources. Should these countries pay an access fee or should the best possible balance be struck between the supply of equipment and the supply of expertise, regardless of the cost? The argument is between those who favour a small charge, which could lead to under-use of the resources, and those who want to maximize the social benefit by giving free access to them (David, 1997). It would be in the interest of the global community of nations and of scientists for the latter practice to prevail.

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Thematic meeting report

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The first part of the discussion by this group was devoted to the clarification and definition of what is meant by the term 'social contract' in the context of the World Conference on Science. In contrast to the past, when mainly French authors used the term 'social contract' to describe relationships between individuals, in today's context the new social contract for science is supposed to describe a partnership between social institutions or agencies. The goal of the contract is to work out the basis of a constructive collaboration between the different partners active in science and those interested in the use of scientific results.

The goal of a 'contract' is to define the basis of the interaction of various partners with potentially very different needs and interests. 'Science', for example, needs freedom to function optimally. Scientists want to understand the basis of our universe and must be allowed to explore new ideas. Their results should be freely available to other scientists to improve the general pool of knowledge and to stimulate further progress. Basic science needs a long-term commitment and a positive outcome can never be guaranteed. 'Society' on the other hand needs to integrate the results of science into a common project where science has to become compatible with other social requirements. When confronted with problems, society generally calls for rapid action on the part of science; it wishes for short-term results and economic returns in exchange for the investment of public funds.

These different basic needs seem at a first glance incompatible. The goal of the 'new social contract' is to attempt to bridge this enormous gap. In fact, the 'contract' somehow results from the desire of the different partner organizations to define a 'common good' of a global nature that they are willing to defend. In the interest of the promotion of this common good, each partner might agree to limit the realization of individual needs, recognize the legitimacy of the interests of the other contractors and accept a limited but peaceful and reasonable satisfaction of all the interests involved. The basis of the formulation of a new social contract between society and science is the agreement by the partners on some specific goals based on common values that have been defined to be of interest for the society as a whole. It is necessary in this process to ensure that the fundamental needs, material and spiritual, of society are being taken into account.

During the discussions of this thematic meeting, different examples were presented to illustrate how the public and private sectors can work together, how these partners should interact with local scientific and non-scientific communities in order to establish a relationship of mutual confidence.

It was pointed out by several participants that education of the public in scientific matters is very important. On the other hand, scientists should become more aware of the needs of society and respond more openly to requests addressed to them. In order to prepare scientists for fruitful interactions with the public, the development of skills in communication should be part of their basic education. Furthermore, evaluations of scientists for nominations and promotions particularly in the academic world focus on the specific scientific contribution of the individual as measured by the list of publications and the capacity to attract grant money. The commitment of scientists to activities devoted to creating a better public understanding of science are not highly valued at the present time. A change in this attitude could in the long run motivate young scientists to participate more actively in public discussions on the significance of science and technology for society.

It was also pointed out that science teachers play a very important role and that they are often inadequately prepared for their task. More support should be devoted to their training. Special courses should be organized for science teachers to bring their knowledge up-to-date so that they are capable of transmitting the principles of new technologies.

The assessment of the impact of new developments in science and technology is a difficult matter, particularly if you need to take into account small effects that might occur with a very low frequency and possibly over a very long time-scale. Recent public disputes over such phenomena as cold fusion or a wide range of environmental issues demonstrate a need for the establishment of recognized authoritative and impartial international bodies which would investigate the extent to which claims are based on established science or simply represent ungrounded opinions put forward by individuals or pressure groups. Such international bodies should provide an authoritative scientific basis for important political decisions.

Science: a legitimate path to understanding

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One of the confounding questions that confronts scientists and non-scientists alike concerns the rightful place of science in our culture. At present, the most obvious and visible effects on our lives are those resulting from the technology that derives from science, and much of public argument over whether science is good or bad is really an argument about the value of technology and less about science. But technology is only one of the fruits of science. Science also affects the way we think, often subtly and sometimes subconsciously, and how we view the world and each other.

When future generations look back to our day, they will envy our generation for having lived in a time of brilliant achievements in many fields, certainly in science and technology. We are on the threshold of basic knowledge concerning the origins of the universe and of life in our bit of it. We are near an understanding of the fundamental constituents of matter, of the mechanism by which the brain works and of the molecular determinants of living things. And scientific thought appears to be applicable to an ever-wider range of social concerns.

Science is at present a small-scale but functioning model of how vastly different members of our society can function in a collective enterprise. There is no such thing as American science or European or Asian science. The essence of modern science is that it proceeds without respect for national borders. An intricate system of formal and informal personal communication has nurtured science from its beginnings, expanding almost beyond practicality during the last fifth of the 20th century. The evolution of the Internet promises almost instantaneous communication of scientific information and achievements for the next millennium. Information will become the world’s cheapest commodity. Alas, creativity, intelligence and wisdom remain as rare and precious as ever. Science, then, is a model system for collective human activity and, therefore, quite apart from the quality and interest of the science itself, the experience is intrinsically heuristic and, therefore, valuable.

So many of the peoples of the world have not tasted the fruits of this intellectual adventure. For quite apart from the tangible achievements science has contributed to our welfare, there are less measurable but nevertheless consequential rewards of scientific inquiry. Who, indeed, denies that the wonders of the universe and the richness of life on Earth are diminished by nourishing that wonder with scientific explanations? Human nature is endowed with a remarkable capacity to wonder, to imagine and to explore – attributes we label ‘curiosity’. Science provides the framework for satisfying that curiosity. Science has several rewards, but the greatest is that it is a difficult, exciting and beautiful pursuit. Some have referred to it as our century’s art!

Society must maintain a vigorously critical attitude towards technological innovation. All attempts to improve our condition must be scrutinized to make sure that they do no harm. In order to survive and progress, humans cannot know too much. Ignorance is not likely to lead to salvation. Humans have been given the capacity to improve their lot along with the obligation to assume responsibility for the applications of knowledge.

Today, there are formidable disparities in how different societies perceive the revolution in biology triggered by the advent of genetic engineering. We are now on the cusp of a new era with unprecedented implications in respect of our ability to influence plants and animals, including ourselves, in fundamental ways. Today we can deal directly with the fundamental source of the properties that distinguish the living from the non-living.

Genes, the fundamental determinants of life’s form and function, are no longer abstract notions, nor are they as enigmatic as interstellar dark matter or black holes. The logic of life, its origin and evolutionary history can now be read in each organism’s genes. Furthermore, many of the conjectures concerning the extraordinary diversity and relatedness of living forms are informed by precise information on the molecular structure, expression and regulation of genes and their encoded proteins.

But the most far-reaching consequence of the molecular-genetic perspective is our increasingly sophisticated understanding of fundamental life processes. Moreover, it is now within our capability to synthesize and modify genes and chromosomes and to reintroduce them into the cells of living organisms, enabling us to reveal the relationship between molecular structure and physiological function. As a consequence, there has been an astonishing increase in our capacity to investigate problems that had previously seemed either unapproachable, too profound, or even beyond the reach of science.

These achievements have radically altered our perspective on health and disease. For now it is quite clear that most, perhaps all, human disease results from changes in one or more genes and the consequent alteration or prevention of normal cellular functions. These discoveries and the promise of others to come have profound implications for the future of medicine, for they have placed us on the threshold of new methods of diagnosis, prevention and treatment of human disease.

The dramatic and extraordinary progress in biomedical sciences has also spawned a thriving biotechnology industry whose list of products benefiting human health and well-being is increasing continually. Hormones, vaccines, therapeutic agents and diagnostic tools are enhancing medical practice. The production and consumption of genetically engineered food plants are realities, although their acceptance as a blessing is being resisted, primarily on cultural and fearsome grounds rather than on documented scientific grounds. In time, however, the perceived risks of genetically engineered foodstuffs will have to be balanced by the needs of growing populations and the economics of crop protection.

The success of relating genes with an organism's characteristics and the benefits from knowing this relationship in still greater detail have paved the way for the international effort to map and sequence the genomes of a variety of organisms including the human. Such maps and sequences for viruses, bacteria, yeast, flies, nematodes, rodents, several plants and humans are in various stages of completion. The aim, of course, is ultimately to understand the genetic basis of an organism's properties, expressed and potential.

Although solving the human genome sequence will provide a richer foundation than heretofore available for understanding the genetic basis of human diseases, some view the outcome as having a dark side. For it has the potential to challenge the concepts of individuality, expose our vulnerability and threaten the very essence of our personal privacy. For we can be certain that, as more and more genes responsible for, or contributing to, human disease are identified, isolated and sequenced, testing procedures for detecting mutations in those genes will be developed. Where these can be done on developing embryo and fetal tissues, they will raise issues about the kinds of decisions that might follow. More and more frequently, tests for diseases that manifest in middle and late life will come on line. The interpretation of tests for late-onset diseases, such as Alzheimer's, Huntington's and cancers, poses complexities that differ qualitatively from those that medicine has dealt with in the past. Even more daunting will be tests for, and interpretations of, gene constellations that predispose individuals to such common disorders as coronary heart disease, diabetes and hypertension and common psychiatric diseases such as schizophrenia and manic depression. Such interpretations will depend as much on the unique genetic endowment of each individual and their environment as on the mutations that are detected by these tests. And coping with such information will be confounded by the absence of therapies other than palliative ones for some of these disorders.

Managing the acquisition and delivery of information about genetic risk will need to address a cascade of personal, professional, ethical and public-policy challenges. For the individuals and families who might avail themselves of these tests, questions will arise about the relative benefits of the knowledge they might gain, given their tolerance of uncertainty and the societal responses to that knowledge. It is important that, as the level of genetic testing becomes more sophisticated and widespread, individuals also be protected against new forms of discrimination and social ostracism.

And we shall have to be on our guard against eugenics with a modern twist: pressures to eliminate individuals with 'undesirable' genetic characteristics or to promote genetic therapies for trivial purposes. In the end, we are likely to learn that each and every one of us carries genes that can have deleterious consequences in certain combinations or under certain environmental conditions. In short, so-called 'perfect' genomes are not likely to exist anywhere. We should not be surprised or discouraged at this level of discourse, for, as with all changes in human thought and technological developments, we are left with new and unanticipated issues. And, as so often in the past, science is challenging traditional ideas and values.

As we go forward from this place, keep in mind that the challenges are great, particularly because the course of science is inherently unpredictable in outcome. We can be certain of only one thing: from future research will emerge major new concepts, concepts that will be as unexpected in their time as was the discovery that DNA alone was the carrier of inherited characteristics. A changing perspective is the history of science and the current hubris is not immune to that imperative.

Moreover, we should bear in mind that the successes that have been achieved do not amount to a complete or even a very profound understanding. On the contrary, current ignorance is vaster than current knowledge. Nothing in the man-made world rivals the complexity and diversity of living things. It is a certainty that there are in nature concepts remaining to be discovered that no one has yet even imagined. In some instances, we have learned enough at least to identify important areas of ignorance. Certain of these concern long-standing questions with regard to development and differentiation, or the molecular basis of mind. Others are new questions, raised by the very achievements themselves. And of course, we should be wary: some things that we now think we know may become less clear in the years to come, or even prove to be utterly wrong.

Views from the electronics industry

Bernt Ericson
Vice-President, Research & Innovation, LM Ericsson, Stockholm, Sweden

Thomas Alva Edison was obsessed by the idea of turning the newly discovered electricity into light. After thousands of experiments with various materials, he finally succeeded when he understood that the glowing wire must be protected from the oxygen in the air.

Scientists started to analyse the light bulb and found some new phenomena that led to the discovery of the electron in 1897 by Thompson. This new understanding of basic science led to the development of the diode, then in 1907 to the triode. The triode is the component necessary to build an amplifier, which was long sought for in telecommunications.

Graham Bell filed the basic patent on telephony in 1876 (the same year Telefonaktiebolaget LM Ericsson was founded) and the use of the new communications technology grew quickly. The distance limitation was given by nature, explained by Ohm's law. Early trials were made to pass the Atlantic Ocean but the high voltage quickly broke the cables. The amplifier allowed New York to be connected to San Francisco in 1915 and in 1956 the first amplified transatlantic cable was inaugurated.

The triode also allowed building of electronic computers, but a huge number of tubes was necessary to build a practical machine. Power consumption and thus heat dissipation was a big issue, but the real limiting factor was the high failure rate of the individual tube and thus the very low Medium Time Before Failure (MTBF). The American military thus strongly requested and supported a radically better amplifying component.

Researchers at Bell Laboratories finally found the answer in semiconducting materials and the transistor was born in 1949. Since then, there has been a constant improvement in the number of transistors that can be integrated into the same silicon chip (quadrupling every three years) and the evolution curve is referred to as Moor's law.

In telecommunications it has always been a wish to be able to communicate from anywhere. The first mobile 'phones from Ericsson, built in 1956 and based on vacuum tube technology, could only be implemented in cars, as the weight was 40 kilograms – without batteries! The increasing integration of semiconductors allows the volume of a 'phone to shrink and has now reached a point where this is no longer an issue.

The accelerometer is an example of how extremely compact sensor systems (today a vital component in all air bags) can be built in silicon. The pet toy Furbie from Japan can communicate by talking and has some limited movements, based on sensors for voice, light and touch – and all for only US$ 30. The newest pet Aido from Sony looks like a dog and can behave like a real dog, including movements.

This evolution will continue thanks to the continual decrease in the distances inside the transistor. We have moved from discrete transistors to integrated circuits and have now reached a point where the possibilities can only be utilized if the complete electronic system is integrated into one single component – the system-on-silicon. As an example, there is ongoing research work to try to build a complete mobile 'phone in one chip.

The focus for the future will then be to utilize this powerful technology to build user-friendly applications. One extremely important application field is the care of elderly people, as basically the whole world is facing an ageing population. Society can't afford to have people continuously involved in this care. A possible solution is to utilize technology to support the elderly to help them lead decent lives especially when they encounter some disabilities.

This summarized evolution of electronics is a good example of how cooperation between academia and industry has resulted in something good for society in general. Industry has possible applications in mind all the time that have challenged academia to better understand the basic phenomena. Based on this knowledge it has been possible to engineer new materials and components.

Within Ericsson, almost 25% of employees are involved in research and development (R&D). As Sweden is a small country, we can't find enough skilled people inside Sweden. Today we have R&D personnel in 23 countries and, because Ericsson is a world leader in mobile communications, it is important to be a multinational company and utilize the best people wherever they happen to be. There is enormous competition going on and the lifetime of products decreases for each generation.

To survive in this war, it is important to enjoy good cooperation with academia and to constantly look for the leading research groups.

Let me finish by saying that this is where I come into the picture.

The engineering and steel industry

Eckhard Rohkamm
Chairman, Executive Board of Directors, Thyssen Industries, Essen, Germany

For all modern communities, the transition from an industrial to a knowledge society is one of the greatest challenges on the threshold of the millennium. Given the vast amount of available insight, the difference between information and knowledge – knowledge as the conscious application and classification of information – is becoming more and more important. This change into a knowledge society is of particular significance in the industry on whose behalf I am talking to you today. Alongside the traditional production factors such as labour, land and capital, the fourth factor – knowledge – is gaining importance for industry. I would even go so far as to say: 'In future, knowledge will become more and more the outstanding production factor'. Education, training and particularly ongoing training of employees are more than ever before decisive in the business development of companies and hence the jobs of the future. I would like to confine my comments to two groups: universities as a part of the educational and research and development (R&D) sector and industry as part of the national economy.

Let me begin with a preliminary comment: it is often said that deep-rooted change is a phenomenon unique to our era and this is of course unhistorical. The 20th century, in particular, has been characterized by a large number of radical changes and structural breakthroughs. It is therefore, in my opinion, incorrect to maintain that only our world is nowadays 'all of a sudden' undergoing such vast change and that it is 'very much more difficult' than the world as it used to be. Nonetheless, here at the close of the 20th century, there are four aspects in which our world differs significantly from former decades and centuries.

The aspect of global competition

Economic globalization has become a routine aspect of everyday business life: for years now, global trade and cross-border investments have been growing much more quickly than individual economies. The framework for this global competition among companies results from the breathtaking progress in information technology and in world financial markets, based on this progress and operating uninterruptedly. Modern information technology, a growing standard of education throughout the world and logistic costs that are continually decreasing enable companies to compete with almost any other location for certain goods from almost anywhere in the world. Accordingly, now and even more in the future, competition will be decided according to criteria that are of global validity. National or even regional viewpoints are taking a back seat.

For companies acting on a global scale, globally located competence centres are gaining in significance. International leaders in high tech are pursuing a strategy whereby their R&D and product development are situated wherever the world's best conditions for innovation and knowledge generation exist for their particular product segment or field of technology. They are not content with locations just about able to keep up in the technology race but seek out those centres of excellence with a character of uniqueness. In other words, competence centres emerge where optimum technology development possibilities converge with good general parameters.

The time factor and the increasing pace at which knowledge is transferred

Based on my professional experience as an engineer and manager, I do not feel that in general the speed of innovation generation has increased. What has increased is the rate at which this information about innovations is disseminated, both in terms of depth and accessibility.

We are certainly all looking to the next basic invention which will open up new fields of application for the business community. The Internet, for example, is no basic invention since it is simply an intelligent interlinkage of existing technology which, nonetheless, will have a vast economic impact.

Whereas formerly it took a very long time for deep-rooted changes to occur, nowadays this process is accelerating to an ever-increasing degree. For example, if the cumulated growth of the industrialized nations over the past decade is taken as 100%, the volume of world trade over the same period has tripled, capital investment across national borders has grown five times and the international volume of the global financial markets has increased more than 10 times. These financial markets especially are directly related to the exchange of information and knowledge dissemination on a real-time basis. The consequence of this is that demands are changing at a faster and faster pace, frequently without any prior announcement, and as a result the time to respond commensurately is getting shorter and shorter. This, I believe, if anything, is the difference with former eras. Nonetheless, I am convinced that a century ago businessmen had a similar impression on the basis of their experience at the time.

The aspect of the information age

What used to be an industrial society is changing at increasing speed into a communication and knowledge society. This speed is largely related to the growing capabilities of computers that are penetrating newer and newer fields. Meanwhile, it has become traditional for computers and automatic machines routinely to process information and control or monitor production processes. This development has been fostered not only by business but especially by R&D and educational establishments for decades now. However, this is present state-of-the art and no longer particularly exciting.

What is new is the explosive growth of new services being rendered by the combination of computers and people. In this context I would mention technical support, life-cycle support and such aspects as personal attention. This is where we have vast growth potential.

One consequence is that the internal structures of the world of work will change even further. In future, hierarchies will find themselves displaced by networks. Competence and knowledge will increasingly have to adapt and the concept of ‘a lifetime of learning’ will be more than a mere buzzword, and, in conjunction with creativity, team quality and empowerment will be a daily experience. Nonetheless, I am convinced that the ability of a lifetime of learning, if it is to lead to achievements of excellence, must be based on a solid foundation of knowledge, for example in mathematics or natural sciences. Even the computer is no replacement for comprehensive basic knowledge of such classic themes, especially given that these are also resistant to any change in many fundamental fields. Isaac Newton’s axioms or Maxwell’s equations apply even and especially in the age of the Internet.

The aspect of communication convergence

As a result of communication, our world is converging on itself. New media are networking the remotest parts. Borders are opening up, ideas and information are available everywhere; indeed the flood of information is almost drowning us. Knowledge available anywhere in the world can be accessed almost any time and anywhere. This naturally has repercussions on numerous aspects of daily life. Engineers, for instance, are able to work on the same design contract worldwide and around the clock. On the other hand, over 90% of the money revolving around the globe nowadays has no specific counterpart in terms of goods or value-added services. Indeed, I must admit that such a system does not have its own self-restraining elements, since such systems from a control point of view tend towards instability. It is possible that we have here a situation in which progress in what is viable has outpaced common sense in what is applicable.

What solutions have industry and science and the universities come up with? Have they reacted commensurately to change so far and are they adequately prepared for future change? There is no straightforward ‘yes’ or ‘no’ reply to this. One thing is sure, however: there is ample scope for improvement. Only the pacemakers, the national and international leaders will survive. Those who cannot keep up will be relegated.

Formerly, the idea was to diversify and thus balance out any risks related to the ups and downs of the economy by accessing additional fields of business. Nowadays, expansion is based on a different principle. Nowadays, the priority is to focus on a few strong points, the buzzword being core competencies. These are areas in which groups strive for size. What does not fit one’s own self-perception is simply shed – in a nutshell, active portfolio management. The key targets are sustained enhancement of shareholder value, focusing on profitable and high-growth businesses offering possibilities of leadership among the top three, as well as long-term, competitive, safe jobs.

For international corporations with access to global financial markets, the priority is the enhancement of shareholder value, meaning the maximization of the return on the invested capital from the stockholders' point of view. This sometimes leads to situations where these requirements are interpreted as the return to some old-fashioned capitalism.

Under these circumstances, the question arises: what are the primary duties and targets of business? Eliminating jobs always means reducing experience and knowledge but mostly in areas where competition has been lost. And as new jobs normally do not arise where the others have been lost and even then not for the same people, this can lead to social tensions and the feeling of being manipulated by outside powers without a face and responsibility. Therefore, every effort to enhance competitiveness has to be undertaken to minimize these results. The transfer of know-how between universities, on the one hand, and industry, on the other, is one way of enabling business to keep up in the international competition for new products, technologies and services, and even assume a position of leadership. Some examples follow where knowledge transfer is of the essence.

We are all aware that the classical, predictable career is a thing of the past and that individual flexibility is the order of the day. Yet such flexibility must be given the opportunity to facilitate the individual's leapfrogging from one stage of his career to the next. A lifetime of learning is always the foremost consideration. Besides their curriculum of initial studies, universities must also open up the possibility of allowing people at work to return to the universities and learn efficiently. MBA courses of study in the USA are one example of such postgraduate arrangements.

Information networks and clusters such as the initiative launched in southern Germany, Business Meets Science, are another possibility. More than 300 institutes, both universities and non-university organizations, were invited to present their research efforts and results to small and medium-sized enterprises (SMEs) and to trade and craft businesses. New technological processes were presented, suitable as solutions to specific problems for SMEs and trade and craft concerns. The second example, in particular, indicates that collaboration between business on the one hand and science and universities on the other is not the sole responsibility of either party but always a mixture of the two.

Business consultants specializing in the transfer of know-how, for example IT, have established themselves as widely respected 'think factories' staffed in many cases by internationally recruited scientists. They pass on their pooled know-how gained from state-of-the-art knowledge at universities and research institutes along with their previously gained experience, thus acting as a catalyst for stimulating progress within industry. They also play a vital role in providing support for young entrepreneurs who are willing to set up their own business activities. Normally, these spin-offs are created by people who are highly talented and motivated specialists in certain leading-edge activities of scientific and knowledge-based know-how but who lack any real business experience and background. To introduce these people to the harsh realities of marketing, finance, cash-flow requirements and taxation problems is equipping them to survive in a competitive environment. Here, transfer of knowledge truly is a two-way street that creates a win-win situation.

Managing knowledge and transfer of knowledge will become a business in itself with vast potential for those nations which lack traditional industrial structures but which are prepared and willing to invest in teaching and learning. The future may well prove that this is the real growth industry.

R&D, innovation and the knowledge-based economy: the Canadian experience

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There are very close and vital links between the three elements in the title of this session and it will come as no surprise to most of you when I say that scientific knowledge and technological change, rather than natural resources, are the principal drivers of economic growth in today's global economy.

The key link, of course, is innovation and that is what I want to talk about today – the relationship between research and development (R&D), innovation and a knowledge-based economy, with particular reference to the Canadian experience. A major point I want to make is that, while Canada is often thought to be a resource-based economy, we have made great strides in recent years to develop a sophisticated, high-tech, knowledge-based economy. This is a real success story.

To start, I need to define what I mean by innovation. My own definition of innovation is a holistic one – from concept through design to implementation. Innovation for me is the entire process by which ideas, discoveries and products are created, developed and taken successfully to the marketplace. Innovation implies both creativity and application.

Traditionally, the innovation process has been described as a linear chain – a sequence of discrete steps that begins with basic research, moves on to strategic research, to applied research then to product development, commercialization and, finally, marketing. The reality is, unfortunately, far more complex. The creation and application of new knowledge is an interactive process with multiple feedback loops.

In fact, innovation is a complex phenomenon which occurs in a dynamic, turbulent environment.

We now recognize that, to be effective at the process of innovation, we must talk of systems of innovation: the linking together of key elements which are vital to translating scientific and technical knowledge into new products and services for society – in other words, effectively putting science to work. At the centre of the innovation system are the innovative companies which take the products to the marketplace. But the firms must be linked to R&D organizations embedded in a science and technology (S&T) infrastructure and have access to highly skilled human resources from universities and colleges to provide the brainpower to drive innovation. In addition, government has a key role to play in setting policies and creating an environment conducive to innovation. Finally, finance and investment are needed at all stages of innovation, but particularly at the development/commercialization point.

Effective linkages, partnerships and feedback between all the players is essential to a fully effective innovation system. Innovation often occurs most naturally at the community or regional level, where it is easier to collaborate and break down barriers, and the greatest impact can be made by developing regional systems of innovation to promote economic growth.

Building up from the necessity of adopting an innovation system approach, I have identified a number of factors related to S&T which I believe a country needs to have in place to develop an innovative economy:

- a strong research base – a long-term investment in knowledge creation – largely a public sector investment;
- focused, targeted strategic research investment in areas of wealth generation (these areas will differ for different countries depending on needs, capacity and potential);
- highly qualified human resources to power the knowledge economy;
- national research facilities and infrastructure;
- effective partnerships between the university, government and private sector communities;
- regional, national and international networks and interconnections between them;
- a modern knowledge and information infrastructure;
- appropriate and effective support mechanisms for innovative technology-based firms, including financial support;
- a focus on technology transfer and entrepreneurship, with a variety of flexible tools and approaches to reduce the innovation gap.

Canada has taken a number of steps to put these pieces in place to promote innovation and has made some strategic investments in parts of the R&D spectrum. But there are underlying weaknesses in our innovation system. To understand the situation, one has to examine the unique structure of the Canadian economy and the nature of the investment in R&D. Compared with its major competitors and trading partners, Canada has not traditionally invested as much in R&D. The pattern of low industrial investment in R&D in Canada is the result of a number of historical factors.

First of all, the Canadian economy has traditionally relied upon natural resources, and natural resources companies, until recently, have not had to invest in R&D and innovation to be competitive. In addition, many of Canada’s largest companies are foreign-based multinationals. When it comes to R&D, most multinationals tend to locate their R&D operations in their home countries. And this has meant that Canadian subsidiaries have been left out of the innovation loop.

It is also true to say that Canada does not do enough strategic R&D – what I call focused, targeted, medium- to long-term R&D in areas critical to the country’s wealth-generating sectors. In a knowledge-based economy, this type of research is critical. Unfortunately, there is too little of this done in Canadian industries at the moment. In other industrialized countries, strategic research is often conducted in large corporate laboratories. In the USA, Dupont Central Research is one such example, IBM San Jose is another. Japan has many examples of large industrial R&D laboratories doing medium-/long-term strategic R&D. Biotech companies have to invest in this way because of long lead times between R&D and the marketplace.

Canada does have some large multinational enterprises which invest in strategic research, but they are few in number and the three largest firms account for fully 44% of industrial R&D in Canada. When you take these multinationals out of the picture, Canada's industrial R&D performance falls far below that of our partners.

So, the profile I have described – a low overall (but improving) investment in R&D, too few large companies investing heavily in strategic research – has led to a unique role for publicly supported institutions including my own organization, the National Research Council of Canada (NRC), to fill the middle part of the research spectrum: to build linkages and relationships with private-sector companies, to fill in for the lack of medium- to long-term corporate R&D.

In Canada, the NRC has programmes and services that cover the spectrum from fundamental to developmental work in targeted, strategic areas of research. Our focus is on medium- to long-term research in strategic areas such as biotechnology, information technologies and manufacturing. We not only perform research, we also provide national facilities, and the research infrastructure that is needed by other members of the Canadian research community. The Canadian Government has also played a key role in fostering the development of industrial clusters at a regional level as a basis for a knowledge-based economy.

There have also been other new investments at the research-base end of the spectrum to promote innovation. For example, our Government has increased its investment in the generation of knowledge by first restoring then enhancing funding to the federal granting agencies for university research and establishing a $ 1 billion foundation to rebuild the research infrastructure in universities and research hospitals. New investments in youth programmes and in a programme of Millennium scholarships for students will help in the development of the skilled workforce needed to support the knowledge-based economy of the future. A new $ 500 million initiative in the health research area – to establish the Canadian Institutes of Health Research – was announced in 1999.

At the other end of the innovation spectrum, Canada is providing support to innovative firms through R&D tax credits and to small and medium-sized enterprises (SMEs) for technology assistance.

Now, if we look back at the list I gave of 'What a country needs to innovate through S&T', there is one last factor which I want to discuss. That is the requirement for good information and knowledge networks. Because of the nature of its geography, Canada has had to invest in good communication systems. Building on this experience, the Government has set a goal of making Canada the most connected country in the world by 2000.

We are building new communication and high-speed, broad-band research networks such as CANARIE (Canadian Advanced Network for Applications in Research, Industry and Education) and NRC's Canadian Bioinformatics Resource, which will allow researchers in government, universities and the private sector to rapidly access the world of genomics information. And NRC's Canada Institute for Scientific and Technical Information, which has one of the largest collections of scientific, technical and medical information in North America, is focusing on the virtual library – the electronic delivery of information to the desktop of its clients.

In summary, the Government is making important investment decisions that will strengthen our innovation capability and will help move our knowledge, know-how and technology across the innovation spectrum and into the marketplace.

My own organization, NRC, has evolved into a knowledge and innovation organization – one which not only carries out leading-edge R&D in key areas, but which also contributes to most of the elements of an innovation system, including hands-on training of the researchers of the future, the national infrastructure for science and technology, technology transfer and the incubation of spin-off and start-up companies, advice and support for the small companies which help drive the Canadian economy and the information infrastructure of the country.

Dr Richard Lipsey, a Canadian academic and specialist, has said about innovation in the Canadian context: 'Many, perhaps most, new industries and products have done their pre-competitive research with significant support from such non-market institutions as universities, government laboratories and with government support'.

In Canada, the model of excellence in the research base, enhancing partnerships and collaboration with industry and establishing a regional and community innovation system, has served us well. We are committed to this as Canada increasingly becomes a technologically sophisticated knowledge-based economy.

Thematic meeting report

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Inputs were given from the government and national research council perspectives, from academia as well as the electronic, pharmaceutical and engineering/steel industries.

That poor and disadvantaged countries need help was the clear message coming from a former science and technology minister from the developing world. These countries would not be able to take over their responsibilities in assisting in the global scientific effort without necessary support from outside, in spite of the fact that they themselves would have to bear a minimal share. A few emerging economies are in a better position and are already effectively participating in the global scientific endeavour within their own possibilities. But much more can be done.

The Vienna plan of action (1979) was discussed. It was emphasized that, for the participants also present in Budapest, it had been and still was deplorable to see that no tangible measures had resulted from that event. After Budapest, the action plans formulated should be implemented to make sure that the desired aims were reached within the shortest possible time. An implementation mechanism should be set up for this.

From the electronic and pharmaceutical industries, it was stressed that development of new products and/or services was actually a translational process starting out with knowledge taken from an appropriate knowledge-generating reservoir. The academic community constituted this reservoir. Generation of new knowledge was brought about by research driven by the passion to understand. Due to the fact that industry would not be able to finance basic research in academia in a major way, funding of fundamental research was heavily dependent on public funds. From the engineering and steel industries, it was expressed that aspects of globalization, the increasing importance of the time factor and the rules of the information and communication age were continuing to exert strong pressure on industry. The focus had to be on developing core competencies and it had to be assured that an active portfolio management could take place. The key targets were sustained enhancement of shareholder value, focusing on profitable and high-growth business offering possibilities of worldwide leadership, as well as long-term, competitive and safe jobs. Support for research and development (R&D) within industry and in academia would have to be provided in this context.

The important role of small and medium-sized enterprises (SMEs) in the innovation process was discussed. They are already of prime importance today, particularly in newly emerging, rapidly developing areas like biotechnology and information technology; and their influence in production and innovation will increase. Managing knowledge and transfer of knowledge will become a business in itself with vast potential for those countries which lack traditional structures, but which are prepared and willing to invest in teaching and learning. However, for this to happen, endogenous capacity-building and science education is vital.

Last but not least, industry representatives made clear that, in their view, the dialogue between all the parties interested in innovation had to be intensified substantially. The partners in this discussion should include society and with it the media, government, academia/university, as well as industry.

From academia, the revolution in biology was highlighted. The logic of life, its origin and evolutionary history can now be read in each organism's genes. Furthermore, many of the conjectures concerning the extraordinary diversity and relatedness of living entities are resulting from precise information on the molecular structure, expression and regulation of genes and their encoded proteins. The molecular-genetic paradigm is dominating vast fields of research to the extent that even a brief look at journals in such fields as diverse as chemistry, evolutionary biology, palaeontology, anthropology, linguistics, psychology, plant science, forensics, information theory and computer science shows the influence of this new research area.

This progress in biosciences has also spawned a thriving biotechnology industry whose list of products benefiting human health and well-being is increasing continually. The production of genetically engineered food plants is a reality.

Concerns were also voiced that academic institutions involved in generating knowledge were now increasingly being invaded by commercial interests and this could have a highly negative impact on the conduct of basic research as it had been carried out up to now.

Using Canada as an example of a country with few R&D-intensive companies, it was illustrated that increasing focus on developing networks and partnerships had led to an enhancement of R&D capacities and to the building of industrial clusters at a regional level as the cornerstone of a knowledge-based economy. The point was made that there was a unique role for government and/or the respective national research council to play in this regard. Over the past five years, the Federal Government of Canada had made a number of strategic investments in the creation of scientific knowledge and in the development of the innovative capacity of its citizens.

During the subsequent lively discussion, a plethora of interesting topics was touched upon. In this report, we will focus on two of them.

The issue of biodiversity and bio-prospecting in bio-affluent countries was discussed. It was stated that there should be equitable benefit-sharing between the bio-affluent regions and/or countries and indigenous communities who had conserved this wealth, on the one hand and, on the other hand, the pharmaceutical companies developing, launching and selling the final drugs. It became evident that intellectual property rights (IPRs) as formulated in the World Trade Organization (WTO) Agreement in force since 1995 and IPRs as characterized in the Convention on Biological Diversity on the occasion of the Earth Summit in Rio de Janeiro (1992) and developed in subsequent discussions were at least partly in conflict with each other. Examples show that some bio-affluent countries have been successfully developing their own IPR culture. This should allow them to participate in the rush towards new diagnostics and pharmaceuticals. In order to achieve an appropriate financial back flow to the region/ country, an endogenous scientific infrastructure has to be present, serving as a platform for interactions with global companies.

The message was put forward by emerging economies with established scientific infrastructure that multinational companies should invest in R&D in emerging economies. This assistance should particularly focus on those countries where the said companies were engaged in ongoing substantial operational activity.

Concerns were voiced from academia. Collaboration with industry and the high interest of some academic institutions in taking patents at an early stage are increasingly impeding the successful generation of new knowledge. In the discussion the view emerged that there is no clear-cut boundary between basic and applied research. Rather, there is a continuous transition, or in other words basic and applied science are placed in a continuum, having pure basic research at one end and strictly product-oriented research at the other. The two cultures are not superimposable and a merger of the two would produce a breakdown of the whole innovation process. At the basic sciences' end, research is driven by the passion to understand, is open to serendipity and is based on rapid peer-reviewed publication. In following this philosophy, it can be ensured that results swiftly become accessible to everybody and basic advances in knowledge are transparent. The other end relating to applications has, due to the proximity of the market, to progress towards specific research aims envisaged in a straightforward course, following the rules of normal milestone and time management. The art is to have both cultures coexisting and flourishing, and at the same time also to have appropriate links guaranteeing an efficient flow of knowledge from academia to industry. Success in achieving this will be the key for sustained progress in the future.

The messages formulated by the panel read as follows:

- Every country should make a commitment to supporting education and research. On top of this, affluent countries should be responsible for assisting the disadvantaged and poor in the fulfilment of their commitment through open-ended rather than tied support.
- The discussion between the stakeholders of innovation, i.e. society, governments, academia and industry, should be intensified.
- Governments should increase their funding of basic research as well as funding for the various areas that can be defined as a public good.
- There is a unique role for governments to play in the development of networks and partnerships aiming at the emergence of a high-tech and/or knowledge-based economy.

Adding value to national research: a need for glue money and development of new partnerships

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International collaboration in science

Scientific research is an international endeavour by its very nature. Yet its funding is predominantly a responsibility of individual national funding agencies. This situation has worked relatively well as long as collaboration has been a matter of individual scientists in different countries, although travel money and sometimes visa and other problems create barriers. As the requirements for large equipment going beyond the capabilities of a single nation have increased, new funding mechanisms have been developed. Examples are facilities governed by a treaty (e.g. the European Laboratory for Particle Physics, CERN, or the International Space Station), or an agreement between organizations (like the European Synchrotron Radiation Facility, ESRF). Political considerations (strengthening European competitivity and creating European unity) led to the creation of the European Union (EU) Framework programmes as a successful mechanism for regional scientific cooperation. Science funding mechanisms transcending national boundaries become necessary as the scale and complexity of scientific problems increase and because global-scale societal problems require global scientific cooperation. The light forms of coordination and networking as in programmes of the European Science Foundation, the United Nations and ICSU are no longer sufficient. In particular, at the global level there is a need for new innovative mechanisms. A prime illustration of this need is global environmental change research.

Global environmental change research

Human activities are increasingly impacting on the Earth's environment on a global scale: conversion of land cover, modification of the carbon and nitrogen cycles, accelerating loss of biological diversity, changes in the atmospheric composition and climatic change. No regional or local environment is immune to systemic changes in Earth system functioning. The scientific effort required to understand these changes and their effect on the future evolution of the Earth system is beyond the scope of any one country or region. Thus, this scientific challenge must be tackled at the global level, which requires an international research effort of unprecedented collaboration and interdisciplinarity. It also requires new forms of capacity-building in order to ensure full participation of developing countries.

The international scientific community has developed a set of four global research programmes in response to these scientific challenges. The World Climate Research Programme (WCRP) deals with understanding the physical climate system, its evolution and variability; the International Geosphere-Biosphere Programme (IGBP) addresses the biogeochemical aspects of global change; the International Human Dimensions of Global Environmental Change Programme (IHDP) has developed a research agenda on the role of humans in causing global changes and how they are affected; the DIVERSITAS programme was created to address the causes and effects of the loss of biological diversity. The essential role of developing countries was realized early on and, as a result, the global change System for Analysis, Research and Training (START) has been initiated by the international programmes. START helps build endogenous capacities in developing regions of the world, so that they can participate effectively in research projects of the international programmes. START also promotes interdisciplinary research at the regional level through the regional networks.

The added value of the international programmes

Characteristic of these programmes is their large scale and multidisciplinarity and their light central scientific management structure. They are very resource efficient because they build on a large body of existing and planned global change research at national and regional levels, to which they add considerable value by:

- providing a framework for priority-setting through an internationally agreed coherent research agenda;
- providing a framework for efficient allocation of scarce resources (e.g. ship time, buoy arrays);
- stimulating scientific network-building;
- developing common methodologies and experimental protocols;

- organizing model intercomparisons and data standardization;
- providing a framework for the development of operational global monitoring systems;
- executing synthesis and integration of individual research project results;
- providing essential inputs in the Intergovernmental Panel on Climate Change (IPCC) process and the transfer of results to the policy community and the public at large.

Present funding mechanisms

Research projects are funded from multiple – mainly national or regional – sources. In the early 1990s many countries created special programmes for global change research. Now, increasingly, projects and programmes are funded in competition through regular mechanisms. A survey by the International Group of Funding Agencies (see below) has shown that the total level of global change funding is about US$ 2 billion per year, excluding ships and satellites. About two-thirds of this research is in some way linked to the international programmes.

Central scientific management such as the work of the scientific committees, scientific synthesis and transfer of results is funded through a variety of (informal) contribution mechanisms. The WCRP is funded by the World Meteorological Organization (WMO), i.e. through the national Met offices. IGBP and to some extent IHDP are funded through a voluntary contribution scheme within the framework of ICSU, i.e. through the science academies and research councils. Capacity-building is funded from several *ad hoc* sources: national, regional, United Nations and development assistance agencies.

The science funding agencies and ministries in about 25 countries and the EU have created the senior-level informal International Group of Funding Agencies (IGFA) to address resource issues of the international global change programmes, such as the phasing in the light of available resources, the optimization of the allocation of national resources and specific funding problems. IGFA is mainly a platform for communication: between the member agencies, and with the international programmes and their sponsors. Conclusions reached in IGFA are not binding, but are taken home by members and used in the national decision-making process.

The need for ‘glue money’

There are signs that the present funding system is under stress. Existing funding mechanisms have difficulty coping with the integration and synthesis of results obtained throughout the individual programme elements and even across the international programmes. Such integration and synthesis is a scientific collaborative activity, often involving scientists from many different countries. It is a critical element for the success of the programmes. There are basically two types of scientific integration activities that require support:

- a series of important, but small-scale integrating activities (integration workshops, synthesis paper-writing, etc.) through which value is added to the projects conducted under the umbrella of international programmes;
- the (sub)programme offices which support the scientific committees and which play a key role in the implementation of the integrating activities, usually staffed with about five scientific officers and postdoctoral researchers.

The funds to support scientific integration activities – which may appropriately be called ‘glue money’ – are only a very small percentage, usually 1-2%, of the cost of the individual research projects. The return on this investment – in terms of an enhanced rate of increase of scientific understanding and a more secure set of scientific results – is many times the value of the costs of integration. Good examples of integration and synthesis requiring glue money are the carbon assessment currently undertaken by the IGBP, which will yield a state-of-the-art review of scientific knowledge on the global carbon budget, and the CLIMAG project initiated by START and WCRP. CLIMAG will bring together the knowledge on climate variability and agricultural production from WCRP, IGBP and IHDP.

Much of the glue money required by the international global change research programmes can be obtained through existing national and international funding mechanisms, such as postdoctoral positions, workshops, research grants for joint modelling studies, etc. These can be obtained via the normal competitive peer-review process by scientists working as core project task leaders or network coordinators.

Finding the sustained funding for the central offices is much more difficult, yet it is essential for the glue money approach to work. Experience in IGBP has shown that core projects with an adequately funded and staffed office system are successful in using the glue money approach to achieve most of their objectives; those without an effective office support system are much less successful.

The programme management of the international programmes must spend an inordinate amount of time on fundraising. This can only be avoided if the different funding bodies are able and willing to commit to supporting the central activities of the programmes at the required level. Of course, this can only be expected if the quality of the programme content and of its scientific leadership inspires confidence. A framework for international resource coordination, such as IGFA, is a necessary but not a sufficient condition.

There are basically three ways in which scientific integration activities can be supported through glue money. Scientists can be encouraged to include requests for glue money in their research project proposals to national funding agencies with the objective of aggregating these small amounts of funds to support substantial international integrating activities. Or, national funding agencies could either create national glue funds for which scientists could apply directly or accept, through their regular competitive review process, proposals from scientists to conduct specific integrating activities, either on their own or in conjunction with an international team. Finally, glue money could be provided to the international project offices directly by funding agencies.

As integration and synthesis and other value-adding activities become more important, the funding mechanisms which focus on project funding and consider this value-adding merely 'nice to have' or even 'an overhead', instead of essential, are becoming more and more inadequate. Therefore, IGFA has recommended that its members '... provide marginal additional funding for international global change research programmes to improve scientific coordination and to help realize the additional value of the research programmes'.

New partnerships

The IGFA partnership of science funding agencies and ministries was formed to address the broad resource issues connected with the new form of conducting science at the global level. It has become clear that this is not sufficient. The full involvement of developing countries, the interaction between science and policy, and the emergence of public-private partnerships call for a broadening of the IGFA partnership.

The first arises from the essential role of the scientific communities in developing countries in the success of these programmes. Full involvement of these communities requires capacity-building and regional research programmes like START. From a scientific perspective, it is an investment leading to better science due to the broader mobilization of intellect and the scientific inputs, in particular related to knowledge of local and regional processes. From a development assistance perspective, building endogenous scientific capacity is an effective means of strengthening economic and social development in developing countries. In this context, the international programmes and START provide a framework for truly equal collaboration between scientists from developed and developing countries. Finally, full involvement of developing countries is politically necessary. The programmes develop the knowledge which forms the basis for decisions within the framework of the Conventions. It is important that all countries take part in this scientific effort, so that the scientific advice to governments is based on data and analysis which they understand and to which they have been able to contribute. This full involvement requires expansion of the partnership with a role for development assistance agencies (DAAs) and international entities like the World Bank and United Nations bodies. Science funding agencies in the developed countries have a role in funding collaborative research projects. DAAs, United Nations bodies and the World Bank should take responsibility for funding capacity-building within the framework of such research projects and for the investments in the local scientific infrastructure.

An important driving force for the integration and synthesis, apart from the scientific interest, is the need to transfer results to society. More than a decennium of global change research has led to a better understanding of the Earth system and the way in which it is affected by human intervention. It has also taught us that there are essential gaps in our understanding. IPCC was created as a mechanism for integrated assessment of scientific knowledge of the climate system. Its effectiveness critically depends on the quality of the international global change programmes. For biodiversity, no similar mechanism exists. A partnership of the WCRP, IGBP, IHDP, DIVERSITAS and START involving the scientific bodies of the Conventions is called for. At the national level, this should be complemented by a partnership between the science funding agencies and the ministries with leading responsibility for the Conventions. The aim should be to create awareness in the policy community of the role of the programmes, to let the policy community assist in priority-setting from a societal perspective and to develop co-funding mechanisms for integration and synthesis.

Business and industry are increasingly interested in the best available independent knowledge on global changes, because of the implications for their future operations (e.g. the insurance sector and the energy sector). Almost a decade ago the World Business Council for Sustainable Development was created as a platform for discussion in the private sector about its role in reaching sustainable development. Partnerships with the private sector have often been called for and at the national level such partnerships are increasingly developing. The benefit of an expanded sponsorship of the international research programmes by governments, the private sector and independent science funding agencies is that it will underline the independence of the programmes and hence strengthen the authority of the results. It would provide the private sector with early information on new developments in a useful format. The private sector could bring to the programmes its experience in running large-scale global operations. Companies could also provide access to certain unique experimental facilities or global datasets, or could make available, for example, aeroplanes or drilling platforms as carriers for experimental equipment. Finally, the possibilities for developing co-funding mechanisms – which have evolved in several countries – should be explored.

Summary and actions

The scale and complexity of scientific questions in global change require an unprecedented global collaboration of scientists from a broad range of disciplines, both in the natural sciences and in the socio-economic sciences. The international programmes in this area add considerable value to national research and do so very cost-effectively. While the mechanisms for research funding – mainly national or regional – are largely adequate, there is a need for more stable mechanisms to support the value-adding activities, requiring less effort in fundraising by the scientific management.

Funding of these activities should be seen by science funding agencies and ministries as being at least as important as the funding of individual research projects, and measures should be taken to facilitate this. Global change scientists should carry this message to their research councils.

The societal significance of a better understanding of global change means that new partnerships must be forged: at the international level between the programmes and the scientific bodies of the Conventions; at the national level, the science funding agencies should take the initiative to develop partnerships with policy ministries and agencies with operational environmental tasks and with the private sector.

The essential role of developing country scientists can only be realized through a partnership of science funding agencies, which are able to fund collaborative research with and in developing countries, and development assistance agencies, United Nations bodies and the World Bank, which have a mandate for funding capacity-building. Developing country scientists should take action to stimulate their governments to put global change environmental research on the agenda with the donor agencies.

The World Conference on Science has agreed upon a *Framework for Action*. This paper contains concrete proposals for action in the field of global environmental change. ICSU and/or UNESCO could bring these actions to a next stage by organizing a focused meeting on new partnerships with representatives from each of the communities mentioned above. Alternatively, a group of countries or organizations could take the lead under the *Framework for Action*.

S&T cooperation and the role of Asia

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Following the founding of modern science by great scientists in the 17th century, science evolved from the pure pursuit of truth to an industry closely linked to technology, which is in fact the practical application of science. The fruits of the development of such science and technology (S&T) have enriched humankind, radically changing the way in which we live and vastly expanding the range of human activities. At the same time we are confronted with new issues arising from the negative effects of S&T development of the 20th century such as global warming, the arms race, excessive consumption and the loss of cultural identity. It is indeed necessary to consider seriously how to deal with the results of over-development of advanced systems to the point where they can no longer be controlled. The optimistic view that 'science is everything', which pervaded the simpler days of the 19th century, fell by the wayside in the latter half of the 20th century and we are now witnessing changes in our scientific and technological outlooks.

Factors behind changes in perception of S&T

I would like to point out six factors that lie behind the changes of general perception on S&T:

- The first factor is unbalanced scientific and technological development. There is a widening disparity between the nations of the world whose peoples enjoy the benefits of development of S&T and those who do not. Even now, as we stand on the threshold of the 21st century, World Bank figures indicate that 3 billion people still subsist on less than US$ 2 a day; our forests are shrinking at a rate of 0.4 hectares every second; 1.5 billion people have no access to clean water; 2 billion people have no sewage facilities; and 1.3 billion children cannot attend school. As the gap between the rich and the poor continues to increase, the world is questioning the responsibility and ethics of scientists and technologists.

- The second factor is that S&T are becoming increasingly specialized. As a result, it has become more and more difficult to establish dialogue and mutual understanding between ordinary people and scientists and technologists. This disconcerting, increased specialization of S&T has resulted in ordinary people feeling that science has become more and more distant and removed from them. Is that not why S&T are today accused of being devoid of humanity, of leaving the human element out of their perspectives?
- The third factor is the colossal growth of S&T. Monumental growth in S&T that accompanied the military rivalry of the USA and the USSR during the Cold War period resulted in a general suspicion about the objectives of S&T. Nuclear development is one such example. Another point in this regard are large-scale projects, which have become such that their research and necessary equipment have grown even larger and more advanced, requiring a greater budget and expert knowledge in a wealth of fields. This has made it more difficult for governments and researchers from developing countries to participate.
- The fourth factor is environmental pollution. The pollution problems in the 1960s and 1970s were triggered by corporate activities originating from the rapid growth of heavy chemical industries. But in recent years, environmental issues on a global scale have come to the forefront, such as the depletion of the ozone layer, acid rain, marine pollution, destruction of tropical rain forests, the extinction of species of wild animals and global warming. It is indeed the uncertain and irreparable nature of these problems which poses a grave concern.
- The fifth factor is the newly emerged issue of the ‘ethics of life’. The development of life science, including basic medicine, has contributed greatly to the well-being of humanity through the application of clinical medicine. In particular, the fight against communicable diseases in industrialized countries has produced dramatic results. On the other hand, new issues involving the ‘ethics of life’ have emerged, including euthanasia, organ transplantation and artificial insemination. Furthermore, the astonishing developments in molecular biology, which make ‘gene diagnosis’ and ‘gene therapy’ possible, have created an unprecedented situation in the history of science. How far genome research should be allowed to intervene in the mysteries of life and how we should deal with the fears of intrusion by genetic analysis into personal privacy are questions we must deal with.
- The sixth factor is cultural. In order to best use S&T for the sake of humanity in the 21st century, we must acknowledge that the introduction of modern science based on the European system of logic into another region such as Asia, which has a different system of logic, will have a different impact on society. This phenomenon of S&T can be clearly seen by differing reactions to issues such as brain death, organ transplantation and genetic engineering. Even among Western nations, differences exist as to the receptiveness of society to research and the practical use of modern science.

I have mentioned six new problems that have emerged as a result of enormous advances in S&T in the latter half of the 20th century. These problems cannot be solved overnight and they require serious reflection. Still, my hopes for the 21st century are founded on the fact that there is a growing belief among humanity that the only way we can overcome these challenges is for us to take a concerted approach.

Japan is certainly one of the most technologically advanced nations and is fully aware of its special responsibility to cooperate internationally. Japan has taken several initiatives globally and regionally. I have prepared an eight-page paper entitled ‘Japanese international cooperation in the field of S&T’, which is a summary of the global and regional cooperation programme for S&T that Japan has undertaken. Here, I merely give a few examples.

Japan’s three-part cooperation framework

Firstly, G7 and G8 Summits and the United Nations (UN) and other international organizations have formed a basis for Japan to develop global cooperation in S&T. For example, at the 1987 Venice G7 Summit, Japan proposed a Human Frontier Science Program (HFSP), which has since been implemented by G7 members. In 1994, in an initiative aimed at combating problems of population and AIDS, Japan announced a seven-year programme of Official Development Assistance (ODA) totalling US$ 3 billion. In 1998, the Japanese budget provided for the establishment of a trust fund for ‘human security’ within the UN, targeting areas which include poverty, narcotics and refugees.

Secondly, I would like to mention bilateral scientific and technological cooperation. For example, Japan has bilateral agreements to cooperate at a scientific and technological level with 30 countries. In addition, Japan is now a member/donor of ODA, which has been extended to include more than 100 developing countries. Japan's ODA is broken down into three types of cooperation: concessionary loans, grant aid and technical cooperation. Through technical cooperation, for example, Japan provides for the training of individuals, the establishment of projects and participation in developmental research. All three types of cooperation do contribute to promotion of S&T in developing countries. Furthermore, the Science Council of Japan promotes scientific exchange within the Asian region.

Thirdly, proactive approaches are being taken by non-governmental organizations and non-profit organizations in the field of environment and medicine.

S&T cooperation in Asia

Let me turn to scientific and technological cooperation in Asia. Japan has also taken several initiatives in the region. Technology transfers effected through partnership between Japanese corporations on the one hand and Asian governments, corporations and workers on the other hand, have contributed to the elevation of technical standards of Asian countries. Another example is Japan's contribution of approximately US$ 280 000 to the Trust Fund for UNESCO scientific projects. Furthermore, within the framework of the Asia-Pacific Economic Cooperation (APEC), Japan participates in the Working Group on Industrial Science and Technology, and has hosted the Science and Technology Ministers Meeting. In addition, since 1976, the Japan Society for the Promotion of Science has been working to develop scientific exchange with Asian countries in the form of university alliances.

'Living together' and 'human security'

I have at some length reflected on the last 50 years of development of S&T. I would like to propose from an Asian perspective two concepts: 'living together' and 'human security', as new guidelines for international cooperation in S&T in the 21st century. It is hoped that these two approaches will help resolve the issues resulting from S&T advancement and forge a new relationship between science and humanity.

Living together

In order to achieve sustainable development on a global scale, we have to consider balancing out development across the entire globe. It has been shown that logic that is incompatible with nature rarely brings forth positive results. As opposed to the concept of 'tolerance', which implies passive acknowledgement that one must coexist with others of a different nature, the concept of 'living together' is a philosophical precept through which we can take positive advantage of the existence of others so as to stimulate our own personal development. It is the first step towards the harmonized coexistence between all things, including, from an ecological viewpoint, 'living together with nature'. After all, humans are part of nature. Opposing nature and trying to distort it will only lead to our own downfall. Among the diverse ways in which we conform to various lifestyles as we live together, we must formulate specific guidelines so that we may make the most of our respective individuality, ensuring that we eliminate obstacles.

Based on the principles of human equality and the universality of human rights imperative for 'living together', I feel that it is important to search for methods to ensure that all individuals are able to demonstrate their full potential. An important theme for this is how to build upon principles such as the 1974 UNESCO recommendation on international education for 'respecting the universal values of humankind and cultural diversity', and the 1994 UNESCO *Declaration* at the International Conference on Education, in which two new values, namely tolerance and sustainable development, were added to the existing universal values of freedom, democracy and human rights. It is vital that we have mutual understanding, respect and a spirit of tolerance for others who are different from us. However, further attention must be given to ensure that in the field of modern S&T, we do not force the logic of the 'powerful' onto the 'vulnerable'.

Japan has managed to achieve modernization while maintaining its traditional roots. We see the undercurrent of the spiritual structure of Japanese S&T in the *haiku* poet Basho's masterpiece '*Fueki Ryuko*'. Basho was a great cultural figure in the 17th century who saw that the nature of art lies in the contradiction between '*Fueki*', which means the fundamental unchanging permanence of things, and '*Ryuko*' which means the trends and changes of the era. In other words, although things which should change and things which are allowed to change gradually do change, there are also things which do not change and things which must not change.

The Japanese have come into contact with advanced civilizations and cultures of different natures, and have repeatedly had similar reactions: frank evaluation and acceptance followed by feverish digestion and crystallization as a universal form which must be maintained in daily life. In only 30 years following the end of the Second World War, Japan became a nation founded on technology while still maintaining its traditions. The spirit of observing harmony with nature continues to significantly influence Japanese nation-building efforts, which are themselves founded on modern S&T. This syncretism between tradition and science serves as the bedrock of Japan today.

Human security

A variety of discussions have been held by the international community on the concept of 'human security'. With the emergence of a growing number of threats, Japan has set out its ideas behind strengthening international approaches to achieve our objectives of ensuring human life, lifestyles and dignity in the form of 'human security'. 'Human security' requires the creation of new frameworks and common rules, the organization of a framework within which we can make a collective response and the provision of funding and human resources. In responding to direct borderless threats to our peoples, it is expected that in the 21st century the citizens of the world will form a more important body in the international community.

S&T in the 21st century

The ultimate goal of science is to focus on humanity. Therefore, we must consider the development of S&T in the context of our social life. In order to make the 21st century a century of peace and prosperity built on human dignity, we must ensure that we avoid S&T development which ignores the general public. To this end, natural science, human science and social science must cooperate. Technology is not an end in itself but the means to an end. The ultimate goal of science is the application of new technology for the good of humanity. Issues concerning nuclear power, computers, medicine and medical care cannot be resolved by technology alone. And issues of brain death and organ transplantation are related to the basic sense of ethics, which sets out our moral values and our view on human life. Answers to these issues are not found by mere advances in scientific know-how. In other words, we will be able to resolve such issues appropriately only if we have an accurate basis of scientific knowledge.

Under a democratic system, important decisions, such as the enactment of legislation that affects the public interest, must have the support not only of legal experts and philosophers but also of the majority of people. To this end, the role of science journalists, who bridge the gap between experts and the general public, is very important. This is why the UNESCO Kalinga Prize for the popularization of science has been so highly commended.

S&T in the 21st century will be concerned with the progress of biological science, molecular biology and biotechnology, and humanity. In particular, as we enter an era in which the notion of state sovereignty takes on less meaning, we must search for a sense of values appropriate to such developments and advocate them as educational themes. To this end, the role of UNESCO will grow in importance.

UNESCO must become an arena in which experts can meet from around the world – a forum for free discussion among scientists, technologists, philosophers, jurists and cultural anthropologists who listen to the opinion of citizens from around the world. When we think about how best to use S&T for the sake of humanity and develop a new relationship with humanity, I would like to reiterate the importance of the concepts 'living together' and 'human security'.

Management of new mechanisms for funding science

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During the past few years, it has become common practice to use various and sometimes original funding mechanisms and instruments to develop science. New funding sources have been added to the rather old administrative funding system. By 'administrative financing' I mean a system consisting of using institutional resources in a non-competitive manner, without evaluation by peers, to finance one's own investments, training of personnel and research programmes and projects. The list of new mechanisms is too long to be examined here and is not the purpose of this presentation. The issue here is the impact, positive or negative, which these new financing modalities have or could have, and the ways in which its positive effects could be increased and its negative ones prevented, while at the same time maintaining the quality and the coherence of the scientific work.

To begin with, a definition of what is meant by 'financing science' is needed to analyse the impact. It is obvious that we are not referring only to research projects.

The financing of science covers *inter alia* support for investment in installations and equipment; institutional development; training and updating of scientific and technical personnel; running costs; diffusion and promotion; education for science; scientist mobility and meetings; setting-up of networks and communications systems, etc. This list is not only non-exhaustive, it does not include a series of additional activities that should be considered when referring to the use of knowledge or ‘research and technology development’ with its social, entrepreneurial and market aspects altogether alien to the scientific venture.

This recount is indispensable, since it is clear that not all financing instruments, new or traditional, are equally adequate to finance all the activities which jointly, and only jointly, favour the development of high-quality science. As we know, it is true that certain instruments or funding mechanisms used in an inappropriate manner can have a negative impact not only on scientific activities as such, but also on other areas such as higher education which we wish to preserve unharmed.

It is also well known, for example, that the international credit secured by a development bank is more likely to finance the installation of infrastructure and training of personnel rather than specific research projects. The competitive funding mechanisms, in turn, finance, with some exceptions, specific research programmes and projects rather than installation of expensive and multiple-use equipment such as new telescopes or new particle accelerators. The latter requires public funding or forms of large-scale international cooperation.

On the other hand, developing multiple-effect financing mechanisms, albeit not unlimited, is also feasible. A competitive fund can finance specific research as such and also training of personnel, diffusion and international mobility. A contract with a firm can support just the preparation of the technical reports or, as well, the installation of certain equipment to outlast the duration of the contract and even result in scientific breakthroughs.

Negative impacts of certain funding mechanisms

The most important issue that needs to be highlighted is, however, the handling and foreseeing of negative impacts of certain funding mechanisms on the various activities associated with science.

It has become evident in past decades that financing research by means of competitive funding often has a negative impact on undergraduate courses in those universities where research fellows teach undergraduates. These researchers are not interested in teaching and often hand over teaching to lower-rank assistant lecturers. This is, if not justified, at least understandable in view of the tough competition that prevails to obtain ongoing funding in open competition, particularly when the duration of the approved project is short. Furthermore, the rewards offered to researchers (salaries, recognition and prestige, travel, etc.) are more associated with investigation than teaching.

The growing practice of funding research and studies under contract with private firms and other institutions also poses problems. These contracting firms mainly demand short-term technical services, for which reason it is difficult to conduct high-quality research associated with these agreements. There are, obviously, associations with private enterprises that produce high-level research but this is not the most frequent case, particularly when it concerns average-ranking universities which are by far the most numerous.

On the other hand, it is well known that the quality and competitiveness of the investigations tends to decrease when these are financed through ‘administrative-bureaucratic’ channels, i.e. not on a competitive basis, but by straight regular budgetary allocations from the institutions. This administrative procedure is nonetheless crucial to maintain the institutional functioning of the environment where the scientific activity is carried on. Sometimes forgotten by the scientists themselves, this factor is essential to generate the necessary atmosphere that stimulates scientific endeavours and is often an important differentiating element between institutions of the developed world and those of developing countries and thereby stimulates ‘brain drain’.

Although common knowledge, it is impossible not to mention the negative impact that certain types of scholarships have on brain drain. The format, duration and conditions of certain training courses for staff coming from developing countries favour and even stimulate fellows to stay indefinitely in the host countries.

A last example of the negative impact of certain forms of funding on activities is of a more general character: practically none of the new funding mechanisms for science is open and neutral. Each one carries its own aims and objectives, is oriented towards specific areas of knowledge or directed to certain determined problems or very concrete activities. Therefore, both institutions and researchers certainly have an extensive variety of funding sources available to them for their activities. But this variety of sources is also limited in as much as it does not always respond precisely to the specific needs and requirements of a country, institution or group of researchers. The usual procedure to get round this obstacle is to use the funding instrument available that comes closest to the actual resource requirement, or to choose certain research subjects or areas only because there is funding attached to them. Added to this, when the local financial contribution requested from the state, institution or group is considerable, the result is that, besides having to invest its own resources, science is developed in areas of lesser importance for the country or group, neglecting more vital sectors, areas or activities.

Conclusion

In short, the development and use of funding systems for science, whether traditional or new, must be embedded in a more general vision of state science policy that defines its own priorities, thematic as well as by activities, and allocates funds for financing the 'blind areas' or distortions produced by this veritable 'knowledge market'. This does not exclude exploring or using the new funding mechanisms, but it implies handling very carefully and coherently the multiple funding sources available to finance the variety of activities related to science whose simultaneous presence generates coherent, pertinent and above all high-quality scientific levels.

Financer la science en pays pauvres dans le contexte de la mondialisation : perspectives et défis

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Après la révolution copernicienne, puis la révolution industrielle, qui ont en leur temps marqué d'une pierre spéciale la marche de l'humanité vers son destin, voici que s'achève le XXème siècle et avec lui le second millénaire. Siècle de haute capitalisation de la somme de connaissances à ce jour accumulées, le XXème siècle restera sans doute dans l'histoire le siècle de l'Utopie apprivoisée par le génie humain. En moins de cent ans, les rêves les plus fous d'hier ont pris corps, et chaque jour passé aura vu se réaliser et reculer, grâce à la maîtrise des technologies les plus sophistiquées, les frontières de l'impossible : le modèle Ford s'est vidé de sa magie, et même Frankenstein a envahi le quotidien. Sur terre, sur mer, dans les airs comme dans les abysses les plus profondes, l'homme a donné rendez-vous à l'humanité ; innombrables sont les conquêtes de son génie, la connaissance n'a plus de limites.

La vie s'en est trouvée totalement transformée, le monde étant devenu un grand village, puis, progressivement, une vaste cour de village, globalisé qu'il est par la puissance indescriptible des nouvelles technologies de l'information et de la communication.

Pour autant, toutefois, la pauvreté, la maladie et l'ignorance n'ont pas été vaincues. Bien davantage, notre fin de siècle offre le spectacle désolant, désarmant, d'une communauté humaine contrainte à partager la même cour de village mais vivant et fonctionnant à deux vitesses, une communauté que chaque jour nouveau sépare un peu plus en deux blocs antagonistes, inexorablement. D'un côté, l'humanité des Nantis, de l'autre côté l'immense cohorte de l'humanité des Damnés de la misère, paradoxalement confinée sur la plus grande étendue géographique de la planète, mais désorganisée et démunie au milieu de ressources de la nature qu'ils sont incapables de reconnaître, de localiser, d'exploiter ou de transformer, assujettie à dépendre de la coûteuse générosité des Nantis.

L'explication de ce paradoxe tient en quelques mots : c'est que la Science est puissance, abondance, magnificence. Nature étant synonyme de roture, notre siècle aura ainsi montré que le pouvoir de s'enrichir et de dominer les choses et les êtres se confère par la maîtrise des connaissances. Science, Savoir et Avoir constituent l'absolu secret du vrai Pouvoir.

Le problème n'est donc plus de se demander s'il est opportun que la science se pratique partout où il y a des hommes ; le problème, c'est de rechercher, formuler, définir, adopter et mettre en œuvre des mécanismes pertinents pour pouvoir financer, partout où vivent des hommes, la pratique de la Science. Cette question est loin d'être banale. Elle recouvre tout ensemble des implications relevant de la technique, de l'idéologie, de l'éthique et de la culture, ces trois dernières étant préalables à la première, pour autant que les moyens dépendent et découlent de la volonté des hommes.

C'est que la science a un coût. Dans les pays développés et dominants, ce coût se laisse dégager au bout de choix culturellement assis, parfaitement planifiés en termes d'investissement, soutenus par des stratégies de puissance. Par contre, pour les pays et les nations à économie de subsistance, ce coût est prohibitif. Financer la science y est au-dessus des capacités ordinaires des Etats, dont beaucoup sont, par ailleurs, soumis au harcèlement de la dette du développement, qui s'allège elle-même par de nouveaux emprunts, de nouvelles dettes à moyen ou à long terme, confiscatrices de l'avenir des peuples.

Certes, depuis une quarantaine d'années, beaucoup a été dit, et beaucoup a été tenté pour trouver et mettre en place des mécanismes de financement de la science dans ces pays. La situation évoquée ci-dessus donne à penser que les efforts entrepris de par le vaste monde, tant au niveau des Etats eux-mêmes qu'à celui des institutions et des organisations internationales, n'ont toujours pas porté le fruit espéré, alors même que l'argent existe et qu'il circule, massivement et de plus en plus vite…

Or, aujourd'hui, les ressources de l'intelligence et de l'imagination ont définitivement relativisé l'impact des ressources naturelles ; l'Humanité est entrée dans une phase de mutations accélérées, imposées ou orientées par l'Utopie apprivoisée ; les autoroutes tracées par la Science exercent leur emprise grandissante et dessinent du XXIème siècle la configuration d'une « Société scientifique » fondée sur l'immatériel et le virtuel. Comment imaginer que la majorité de l'Humanité soit exclue de cette société nouvelle qui s'invente sous nos yeux, parfois sur notre dos, et qui nous gère tous ? Voilà le défi à relever.

Minimiser les risques d'exclusion, augmenter les chances d'adhésion, désamorcer les bombes de la misère, repenser le partage de l'essentiel qui gît dans le cerveau des hommes, c'est cela Financer la Science. Nous sommes persuadés que ce défi peut être relevé au XXIème siècle. Dans cette conviction, nous formulons ci-après quelques propositions.

En tout premier lieu, investir dans la culture des partenaires sociaux et des acteurs du développement dans les pays attardés scientifiquement constitue la base des mécanismes de financement durable de la Science au XXIème siècle. Qu'est-ce à dire ? Simplement qu'il n'existe point de fatalité biologique ni de contingence suffisante pour empêcher irrémédiablement une société humaine de devenir une société moderne, c'est-à-dire une société ouverte à la science. Les résultats « miraculeux » engrangés par les sociétés développées d'aujourd'hui ne sont rien de plus que le fruit d'une rigoureuse organisation et d'un engagement raisonné dans la responsabilité et dans la culture. Seul, ce « mécanisme culturel » est à même de favoriser la pose de jalons irréversibles du financement pérennisé de la science dans les pays pauvres. Car, chaque groupe d'hommes imprégné du fait que la science est le principal instrument de son émergence, de sa souveraineté et de son confort amélioré est un groupe capable de mobiliser la collecte des crédits nécessaires pour le développement de l'activité scientifique.

Une fois cette fondation construite, il devient loisible d'imaginer d'autres mécanismes de financement plus techniques. Mais, faute de la construire, toute initiative dans ce sens demeure greffée, imposée, « affaire des autres »…

A cet égard, attardons-nous quelque peu pour souligner sans complaisance ce que nous considérons comme la cause profonde de l'échec des mécanismes mis en œuvre au cours des dernières décennies, au plan national ou au plan international, par le biais de la coopération bilatérale ou multilatérale : grands projets sur cinq ou dix ans, fonds spéciaux ou fondations pour la science, etc. Cette cause réside dans le caractère artificiel des mécanismes eux-mêmes, souvent imaginés, conçus et élaborés – « montés » – par des experts internationaux dont c'était plus ou moins le métier, sans prise réelle ou suffisante avec le tissu social, le contexte ou le lieu d'accueil des initiatives concernées. En outre, la rentabilité économique à court terme a servi quelquefois de base à l'éligibilité desdites initiatives aux financements par des agences ou des pourvoyeurs de crédits fort justement appelés « bailleurs de fonds » et à ce titre amenés à s'immiscer de manière directive et souvent compromettante dans la mise en place puis dans la mise en œuvre de projets ou de programmes de science. L'on a vu de la sorte « bailler des fonds » à des projets à vocation scientifique comme s'il s'agissait de projets de construction d'usines ou de routes « clés en mains »…

S'il ne fait pas de doute que la mobilisation des crédits internationaux doit être encouragée et accélérée, il convient aussi bien que soient révisés les mécanismes et les modalités d'accès, de gestion et de suivi des opportunités de financement qui pourraient s'offrir à l'avenir. Dans cette direction, les objectifs même des initiatives devront être toujours mieux précisés en s'appuyant sur le contexte, l'histoire et le niveau des bénéficiaires autour des quatre priorités suivantes : formation des capacités scientifiques locales, développement des structures, organisation de masses critiques significatives de ressources humaines, sécurisation de la carrière des scientifiques.

Ces objectifs admis, un cahier des charges devrait être institué dans le but de définir de manière précise et contractuelle les efforts à fournir par les Etats bénéficiaires des financements internationaux pour la science, sachant que le développement de cette dernière est une affaire de bonne foi, de transparence et de loyauté qui vise à favoriser dans chaque pays l'accès aux capacités de production des idées et des connaissances par référence aux standards universels.

Le rôle des institutions internationales, l'UNESCO en tête, doit être, à cet égard, de renforcer la sensibilisation des uns et des autres et d'assister les Etats pauvres pour créer avec eux des mécanismes nationaux efficaces d’investissement dans la recherche.

L’un de ces mécanismes alternatifs de financement de la science par les pays pauvres se trouve être le développement de fonds ciblés par filières de production ou par thématiques scientifiques orientées vers la solution de problèmes concrets. De tels fonds ciblés ou spécialisés présentent l’avantage de mobiliser les secteurs concernés par les résultats de la recherche en les associant à tous les niveaux de la chaîne scientifique : conception et définition des thèmes de recherche, constitution des moyens nécessaires à leur réalisation, évaluations d’étape, organisation de la valorisation des résultats… Au Cameroun, cette approche est en cours d ‘expérimentation depuis quelques années dans certaines filières de recherche agronomique à forte demande de technicité. Les perspectives en sont encourageantes dans la mesure où s’associent harmonieusement dans cette expérience l’Etat, le secteur privé national, la coopération scientifique et financière bilatérale et internationale.

A ce jour, l’expérience a permis d’atteindre deux résultats significatifs en matière de financement de la science : le premier, c’est l’entrée dans les usages du concept de « partenariat financier sur programme » ; le second, c’est d’établir qu’à partir d’un tel partenariat on peut constituer progressivement un fonds autonome de sécurité pour la recherche et, si modeste soit-il, pérenniser ainsi l’activité scientifique dans le secteur concerné. Une troisième idée découlant de cette expérience, c’est que, dans un pays donné, des fonds de cette nature puissent fédérer graduellement leurs réserves afin de constituer à terme un fonds plus important sur une base thématique ou générale, à l’échelle régionale ou nationale.

L’expérience évoquée ci-dessus montre par ailleurs que, dans les pays pauvres, la générosité des donateurs peut être capitalisée dans le cadre d’actions ou d’initiatives revêtues du sceau du sérieux. C’est là une donnée rassurante, car nous sommes persuadés que même les plus pauvres peuvent se cotiser pour constituer le « *seed money* » nécessaire au démarrage de programmes significatifs de science et de technologie. Dans cette perspective, une aide internationale plus importante devrait être la prime accordée aux pays qui se seraient résolument engagés dans l’effort national de financement durable de la science, selon un processus où l’argent national « appellerait » l’argent extérieur.

La durabilité des nouveaux mécanismes de financement pourrait alors être garantie par la mise en place, dans chaque pays, d’une fondation nationale pour la science qui, en plus des alternatives imaginées ci-dessus, serait alimentée par les sources complémentaires suivantes : prélèvements sur les budgets de projets de développement publics ou privés à forte intensité technologique, obligations sur les projets industriels délocalisés.

CEOS as a case study of an informal mechanism

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The Committee on Earth Observation Satellites (CEOS) was created in 1984 by major space agencies all over the world. Its prime objective is to facilitate international coordination of spaceborne Earth observation activities. It seeks to optimize the benefits of spaceborne Earth observation through the cooperation of its members in mission planning and in the development of compatible data products, formats, services, applications and policies. Twenty space agencies are currently members.

The unusual feature of CEOS is that it has no headquarters and no budget. It is an example of what John Marks referred to in his presentation as ‘light forms of coordination’. There is an annual plenary meeting hosted by the organization which holds the chairmanship for that year. Its working groups – strictly controlled in number to avoid unnecessary meetings – meet twice a year and report their recommendations to the plenary session.

CEOS is essentially a ‘best efforts’ organization. That is to say, it is not based on any legal convention and it operates by agreement among its members rather than through any juridical obligation. This does not mean, however, that it is without influence in the raising of funds for Earth observation programmes. Once agreement has been reached in CEOS, the individual members need to seek funding approval at home, but this process is undoubtedly facilitated by the CEOS recommendation. It is particularly reassuring to ministers to know that a request for funding is consistent with a recommendation supported by the world’s major space agencies.

The weight attached to a CEOS recommendation has been substantially increased by the inclusion in CEOS of ‘associates’, who are in effect the major user organizations, such as the World Meteorological Organization, the Food and Agriculture Organization of the United Nations, the United

Nations Environment Programme, UNESCO, the Intergovernmental Oceanographic Commission, ICSU and the three global observing systems. There are now 18 such associates and, because of the absence of any formal voting system within CEOS, they are free to take part in all the debates.

This configuration of space agencies and major users marks a very positive development, for it shows that space agencies recognize the need to tailor their Earth observation programmes to meet the requirements of the users – and not simply for their own use. Obviously, there is a downside to an organization which has no legal authority; consensus takes time and there are often compromises to make on the way, but the importance of this sort of informal mechanism should not be underestimated.

Two years ago, this collaboration within CEOS of the space agencies and the user organizations was taken a step further by the creation of what is known as the IGOS Partnership. IGOS stands for Integrated Global Observing Strategy. It is important to understand that IGOS is not a single system, that it is intended to be a framework within which all partners can make contributions on an equal basis. The aim is to build on existing achievements, with additional efforts being directed towards areas where satisfactory international arrangements and structures do not currently exist. It addresses both space-based data and *in situ* data.

The IGOS partners have now formally agreed on the terms on which they will cooperate and the Partnership meets twice a year to push IGOS ahead. The meeting held in Rome in June 1999 agreed that it would proceed by identifying themes, each of which could be carried forward by space agencies and users both interested and able to make some positive contribution. The first theme to be started was Oceans (because it was felt to be more mature than some other areas) and the aim was to have a plan of action for this theme ready for approval at the IGOS partners' meeting in November 1999. Other themes are known to be in the pipeline and criteria have been established for judging whether or not they are suitable for acceptance into IGOS. Foremost among these criteria is the need for the theme to be able to muster sufficient support to show significant progress in a short time-scale. Many of the IGOS partners are convinced that this effort can be of particular value to those who are responsible for implementing and monitoring the increasing number of international Conventions in the environmental field.

The IGOS Partnership is, it is suggested, a useful model for other areas, for it requires no legal instrument and does not reduce the responsibilities of existing organizations. It simply aims to reduce unnecessary duplications and to fill gaps in existing efforts, all of this against the background of requirements formulated by the users themselves and not by the space agencies.

CEOS has been keen in recent years to have a more regular exchange of views with the commercial Earth observation sector and there are obvious areas of common interest. One needs, however, to be entirely realistic about raising research money from the private sector. It can be, and indeed is already being, done, but there must always be some real advantage in the arrangement for the private sector.

This is not to say that the private sector plays no role in the new mechanisms we are searching for. It is simply that the public sector must be clear on the terms which are necessary to interest the private sector in investing its money. That said, CEOS is looking forward to a closer relationship with the commercial sector over the coming years.

In short, this is CEOS and the part it is playing in the IGOS Partnership and this lightweight cooperative structure probably has some lessons for those operating in fields other than Earth observation; not least, that one can be up and running in a fraction of the time needed to construct an intergovernmental agreement.

Thematic meeting report

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Approximately 100 participants attended. There was a general discussion led by six main speakers. Particular emphasis was given to science in poor countries and the role science might play in their relationships with the industrialized world.

The speakers emphasized that:

- the existing national funding mechanisms did not satisfy the needs of the big global multidisciplinary programmes;
- the science community had to show that it was able to deliver results, and to understand that governments, corporations, private industry, etc., wanted a return on their funding;
- there was a need for better cooperation between more partners both at national and international levels, i.e. the science community, the private sector, the public and

governments of industrial and other countries. Partners should take better account of each other's requirements;

- science funding should be provided on a competitive basis, bringing in scientific review, in order to create and maintain scientific credibility;
- it was essential that scientific communities in poor and non-industrialized countries play a role in the international research agenda.

The discussion after the presentations was mostly concerned with how to increase the participation of poor countries in science. It was argued that bilateral and multilateral cooperation on science policy and science-related questions among such countries was of the utmost importance. Even in the poorest countries the public funding of science ought to be increased. One suggestion was to ask these countries to allocate to science some portion of the debt relief offered earlier in June 1999 by the G8. UNESCO would not be an appropriate global funding agency. A suggestion to create a GSF (Global Science Facility) along the lines of the Global Environment Facility was also made. It was difficult to create partnerships between private industry and local science communities in such countries. The impression was sometimes given that the private sector did not need such partnerships.

Formal and informal mechanisms for funding international research programmes already existed. It was argued that, on some occasions, there was a need for more formal arrangements. A proposal to create a more formal partnership between research councils, or agencies responsible for science policy and funding, and countries and regions in all parts of the world was raised and generally supported.

At the end, the Chair put a number of propositions to the meeting which received broad support. These were:

- In looking for new mechanisms, we had to take account of existing mechanisms at a time when science was being challenged and the attitudes of governments, the principal funders, were changing.
- The case for funding science had to be made in terms of achieving a balance of advantage for governments (accountable to their taxpayers), for corporations (accountable to their shareholders), for the general public and for long-term planetary health.
- Part of the process was raising the profile of science on the agenda of such international institutions as UNESCO and United Nations agencies, the Global Environment Facility, the World Bank and regional development banks, and the G8. There was a case for extension of the Cupertino project between research councils. The idea of setting up an Intergovernmental Panel on Science, comparable to the Intergovernmental Panel on Climate Change, might also be considered. In that event, its activities might come under the aegis of UNESCO.
- The principle of partnership in science between governments, corporations and the public should be more clearly recognized. Education in both industrial and poor countries was vital: at present the knowledge gap in science between them was widening. Without greater public understanding of science and greater support for it in individual countries, little progress could be made. The model of the European Science Foundation might be extended to other countries and regions.
- Above all, science had to be seen as useful and justifiable as an instrument of beneficent change. At present, there were global research programmes but no system for global funding. There was a need for a better strategy and clearer setting of priorities. Problems at international level were often reflected at national level. Greater clarity and public participation could reduce suspicion about science and lead to much greater public support for science with accompanying funding.

Scientists in the service of decision-making

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Scientists engage in understanding the world in pursuit of its fundamental laws. Their attention is on the natural world and man-made facilities, as well as on society itself and its institutions. Through their study and investigations, scientists contribute to society's wealth of knowledge. But they must also serve society in a more direct manner, as part of their moral and ethical responsibility and in return for the freedom they are given to pursue their interests. The understanding and knowledge they gain can and should be used in the service of decision-making, to forecast and evaluate how proposed plans and actions (or lack thereof) will affect the natural and built environment and living systems, including man and the other species that inhabit the world.

Geophysics is a case in point. There is a two-way interaction between human activities and the geophysical environment. Geophysical forces originating in the Earth's interior, in the atmosphere, oceans, hydrosphere, atmosphere and beyond have a direct influence on man and the settlements and facilities he creates. Some are short-term catastrophic influences, like earthquakes, volcanic eruptions, floods, hurricanes and tsunamis. Others are longer-term effects, like sea-level changes and land subsidence. Man exerts forces on the environment that have undesirable effects, like air and water pollution, depletion of resources, erosion, increased risk of earthquake damage. Quantification of these influences is necessary as a basis for decision-making. Economics, sociology and political science are additional dimensions to be considered.

Decisions are taken by individuals, groups, agencies, national and international bodies. Scientists should serve all, not merely the so-called 'decision-makers', those who are elected to rule or those appointed by them to manage society's systems. The ordinary citizen is entitled to the support of scientists in making decisions, at least as much as the decision-makers themselves – actually more. It is scientists' ethical and moral responsibility to put their knowledge to the service of all.

Decisions are made under uncertainty. Science plays an important role in reducing the uncertainty and in supporting decision-making under such conditions. Quantification of uncertain outcomes, their probabilities and consequences, facilitates rational decision-making. Also, decision-making is itself a branch of social sciences, which uses mathematical theories and models as aids. Models mainly serve two purposes. First, they enforce a discipline of specificity, since they do not tolerate generalities. Second, a model serves as a vehicle for structured communication between parties to the decision-making process. The process should be interactive and iterative. At each stage, data and positions are put in and the model is run. The results are reviewed, studied, understood and discussed, and data are prepared for the next run of the model. The structured format of the process increases the probability that the list of options is complete, that consequences of decisions are appreciated, that the sensitivity of outcomes to changes in conditions is understood and that the trade-off between different objectives is quantified. The role of scientists is to provide the input to this process and to help all segments of society to pursue it successfully.

Some observations on the role of science in public policy

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This paper[1] is about science and public policy. It offers some observations about the role of science in developing and implementing public policy. The author's perspective is that of someone with experience in university research in engineering who has subsequently worked in government. The object is to understand better the nexus of science and policy and particularly to develop a clear view of the role of government scientists in the formulation of government policy.

In what follows, three aspects of the science-policy nexus are discussed: scientific fact, scientific prediction and the positioning of scientific advice in the process of making public policy.

Scientific fact

Some questions of public policy can be answered only on the basis of a scientific fact. Acceptance of a new result as fact by the scientific community does not come easily. It requires repeated verification of a result through independent, controlled experiments that are successive improvements on the original experiment through error analysis and better design, sometimes changing to entirely different principles of measurement. This sequence of experiments produces results that are expected to be more and more reliable. At some point in that sequence, the scientific community begins to accept the finding as fact. In the context of public policy, the most interesting scientific facts are those that establish links between unfamiliar effects on people and on their environment and the causes of these effects.

Scientific prediction

Very often, the question put to scientists in the context of public policy formulation deals with a pressing problem involving a very large and complex system about which too little is known. The problem itself might be serious and urgent, but difficult to define precisely. The scientists might be asked to predict what might happen and to suggest what could be done about it. Anecdotal evidence may far outweigh the scientific and the problem may, in fact, be perceived to be one thing and turn out to be something else. In these circumstances, the advice is a scientific prediction based on a model of the system in question.

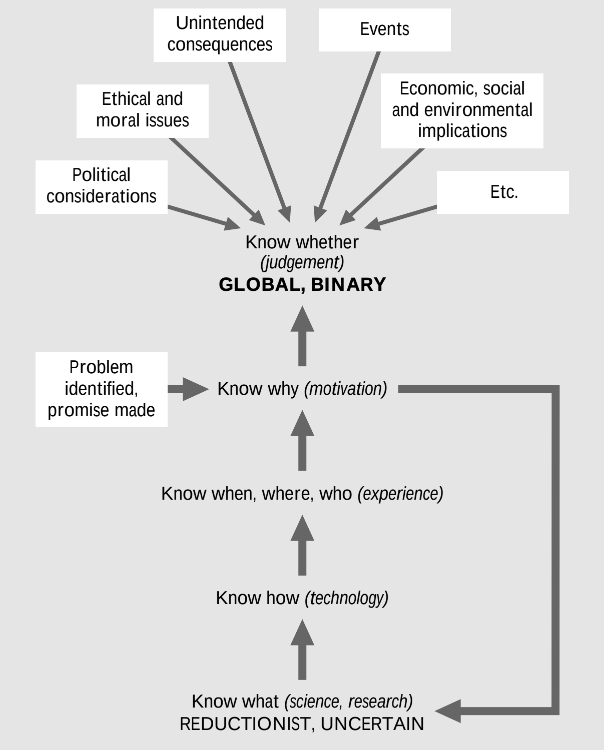
Such a model begins with the component models of the interacting processes that might be expected to be important in determining the behaviour of the whole system. The selection is made on the basis of experience, theory or even intuition. The models of these phenomena are fitted into an appropriate mathematical structure that embodies techniques to convert input information into a prediction. There are two kinds of inputs: measurements and observations of a more qualitative sort. The model is tested against available measurements wherever possible and is improved empirically to make the fit better. It also has to be validated, in full or component by component, whenever the opportunity arises to test it against a controlled experiment.

When the advice arises out of a scientific prediction, the scientists and government must have realistic expectations of one another and of themselves. Government can't expect scientists to give advice with certainty and it can't create the expectation among the public that it can solve the problem on the basis of science alone. Scientists, on the other hand, can't expect their predictions to be treated as imperatives by decision-makers. They must recognize the limitations of their models and acknowledge that there may be cases in which they should be ready to look for other kinds of information (e.g. historical knowledge) that might help deal with the problem.

The place of scientific advice in policy-making

The final section deals with the place of scientific advice in the process of making policy. The framework proposed is a hierarchy of five kinds of issues that have to be addressed in policy-making. These are shown in Figure 1. Starting from the bottom, they are the 'know what' issues; followed by 'know how'; then 'know when, where, who'; 'know why' and finally 'know whether'. Once the policy-making process is launched, this hierarchy represents the order in which questions are actually answered. It can also be thought of as a listing of the questions in order of difficulty.

Figure 1.



The figure also shows the association between the questions in the hierarchy and the factors that enter into policy-making. Science is associated with questions of substance, the 'know what' issues. The 'know how' issues are associated with technology. Answers to the 'know when, where, who' issues are a matter of experience – in the case of government that might be experience in delivering programmes. The next level, the 'know why' issues, deals with motivation. And the final level, the 'know whether' level, calls for judgement and decision.

The 'know why' level, generally, is the level of entry into the policy-making process, as shown in the figure. A problem is brought to the attention of government, a campaign promise made and the civil service is instructed to 'look into it to see what might be done'. The signal goes down from 'know why' to 'know what' and the process starts at the bottom. Of course, policy isn't usually made in one pass through the process and some policy ideas never emerge from it.

Cabinet acts at the 'know whether' level. It decides whether to accept the policy recommendations that come up, in light of all the other considerations it must deal with at that level. These are issues that don't come up through the policy-making process. They include, prominently, other interests – interests that were not included explicitly in the policy process. The name given to the considerations of such interests is 'politics', by no means a pejorative. The possibility of strategic issues and unintended consequences that had not been considered before arise here, as do issues of timing, external pressures and events. Economic impacts of social policies and social impacts of economic policies, and environmental impacts of both that might not have emerged earlier, should come into consideration here. And, of course, there are additional issues such as the constraints of international treaties, consistency with the values and philosophy of the governing party and possibly even with related but still unannounced intentions of the Government.

Finally, we have to realize that there are two complicating incompatibilities between the science at the 'know how' level and the decisions at the 'know whether' level. First, science is reductionist, but government decisions have to be holistic. Science divides problems into questions that can be answered separately, but governments have to try to optimize large interacting systems under a large set of constraints. The second incompatibility is related to certainty. Science cannot produce results with certainty. Even the scientific fact, discussed earlier, is always somewhat uncertain. Scientific advice in the policy-making process is much more uncertain, for reasons already discussed. Yet government decisions have to be binary: a law or regulation either exists or it doesn't.

Conclusion

The conclusion from this is that science has a very important, indeed often essential, place in the policy-making process, but it rarely stands alone. Science generally does not produce policy imperatives or policy prescriptions and scientists should recognize the importance of issues additional to science that must enter into consideration.

Likewise, decision-makers have to be ready to admit that they make judgements and be ready to defend those judgements. They must not claim that their judgements are dictated by science and likewise they must resist any temptation to select those pieces of scientific advice that support the judgement they make for other reasons.

Perhaps no such understanding was needed in an earlier, simpler time. Scientists did science, decision-makers made policy and it probably didn't matter very much if they didn't always work together all that well. But today many of the issues that governments must cope with are driven by advances in science and technology, and the growing impact of human activity on nature requires deep new understanding of many increasingly interrelated phenomena. In this new setting, scientists and governments must work in closer harmony than ever before in developing public policy.

Note

1. The present text is based on a longer paper by the author entitled *The Role of Science in Public Policy – Some Observations*, presented at the Fourth Conference on Statistics, Science and Public Policy, Queen's University, at Herstmonceux Castle, UK, April 1999.

Role of science in the evolution of disaster management

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Disaster management is 'an applied science which seeks by the systematic observation and analysis of disaster to improve measures relating to prevention, mitigation, preparedness, emergency response and recovery'(Carter, 1992). However, this holistic view did not gain wide-spread acceptance until during the last two decades. Prior to this, response and relief were considered by most to be adequate.

Starting in the 1970s, the idea of disaster management, encompassing a totality of activities before, during and after impact of a hazard, with longer-term horizons, began to evolve. In particular, mitigation – reducing the impact of a disaster – and prevention became increasingly important. The realization that many deaths from disasters could be prevented, as well as the recognition of their devastating effect on the economies and development of poorer countries, led to the 1990s being declared the International Decade for Natural Disaster Reduction (IDNDR) by the United Nations. This brought mitigation and prevention into global focus and increased their acceptance.

The role of science

This evolution of prevention and mitigation as critical elements of disaster management has been underpinned by scientific knowledge. It is science, and to perhaps a lesser extent technology, which has made widespread application of mitigation and prevention possible. Advances in seismology have increased our ability to forecast the probability of earthquakes occurring along particular segments of faults. Engineering advances have made it possible to reduce the amount of seismic energy transmitted to a building through base isolation, while data on ground motion collected from earthquakes have been incorporated into revised building codes, thus improving seismic performance of structures.

Mitigation also has a longer-term focus. Geographic Information Systems technology has allowed production of multi-hazard maps, superimposing different elements on the same map. This technology also permits multi-user interfaces, thus allowing planners, decision-makers and disaster managers to use a common information and knowledge base. Risk and hazard maps can guide development away from high-risk areas, thus reducing the probable impact of a hazard.

Improved forecasting and modelling techniques have made long- and short-term forecasting and tracking of hurricanes possible, thus saving many lives. Modelling of floods has also made important strides and resulting flood-risk maps can be used not only to support development planning decisions but also for alerting and warning vulnerable populations. Evacuation of populations at risk based on flood and storm forecasts saves thousands of lives. However, despite the increasing use of these tools, which are commonplace in developed countries, many developing countries are not able to benefit from them.

Gaps in hazard databases, lack of research in basic science and resource constraints on maintaining technology preclude widespread application in poorer countries. In addition, small countries may have too few scientists to create the required critical mass for a vibrant research atmosphere.

It is inevitable that, as pressure increases to balance the need for development against protection of natural resources and vulnerable populations, the use of science will become of greater importance. Decision-makers of the future will face increasingly difficult choices. As populations grow, more development will inevitably move into more hazard-prone areas, thus exposing more persons to the impact of hazards. Protection of vulnerable populations, development and the environment will become more difficult and important. How will science and technology protect these vulnerable populations and infrastructure?

No doubt, improved building technology, better early-warning systems and more stringent design standards will all play their part. Designs that were uneconomical will become economical as potential losses become greater, allowing designing for higher magnitude events. Earthquake forecasting will become more exact and perhaps one day we will have the ability to predict them. There will be increased use of satellites for communications as well as mapping, response and planning. Behavioural sciences will become more important as disaster managers seek to reduce human vulnerability and to better understand responses to warnings as well as perceptions of risk.

The trend has been to develop new tools and to make these tools available to more developing countries. The IDNDR emphasized that all vulnerable developing countries should have access to new methodologies and technology related to early-warning systems and hazard and risk-mapping, but adequate funding was never available for this goal to be met. The real challenge of the 21st century will not be improvements in scientific research but rather ensuring that advances in science are accessible to the most vulnerable, and that the poorest nations do not fall further behind in the knowledge base and therefore in their ability to protect themselves.

The role of the scientist

Many of the challenges associated with the use of science in disaster management are not scientific: mention has been made of the problems of resources, critical mass and political will. However the question must be posed as to whether scientists have an ethical or moral duty to ensure that science is applied for the benefit of all mankind. Is it the scientists' responsibility to 'sell' science to policy-makers, opinion leaders and the public, thus influencing financial decisions and assisting in the securing of funding for continued application of science?

National development must be guided by sound sustainable policies which do not place population and important investments in high-risk areas without adequate analysis of risk and cost versus benefits of mitigation. Planning decisions should be informed by application of scientific knowledge of hazards, their effects, probability of impact and associated probable maximum loss. This understanding of the nature of the hazard offers the best basis for decisions protecting development, populations, infrastructure and environment as well as management of disasters. Disaster managers and scientists must be committed to ensuring that policy-makers understand this message.

Conclusion

The continued evolution of disaster management will depend on disaster managers understanding and appreciating the benefits of science to the discipline as well as helping to sell the importance of science. Disaster managers must also support scientific institutions in accessing resources for application of scientific methodology and technology. They must support interdisciplinary approaches which offer the best opportunity for success and optimum use of resources.

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Thematic meeting report

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Science has a duty to serve society because the world is changing as a result of human activities. Outstanding breakthroughs in natural sciences and fantastic achievements in techniques and technologies realized in the second part of the 20th century have led to a great hope that now almost everything is possible and, on the other hand, to massive mistrust of science and scientists by the population because of growing pollution and environmental problems. The gap is growing between the intellectual communities of scientists and engineers on one side and 'men on the street' and the younger generation on the other. One of the negative results of such misunderstanding is that to a great extent the population is not supporting ideas to enlarge the financing of scientific research and politicians do not always listen to scientists and to scientifically based arguments. A principal change in the presentation of science and its achievements in mass media should be realized.

Understanding the impact of human activities on the environment requires an interdisciplinary and multidisciplinary approach involving the natural and social sciences. Very complex vital environmental issues are one of the strongest challenges in the 21st century and here a comprehensive and thorough scientific approach is needed.

The so-called North-South problem should be minimized through an intensive educational policy in developing countries, which are rich in natural resources but not rich enough in modern, environment-friendly technologies. Very often, the scientific community does not offer alternative technologies to those which are based on exhausted natural, non-renewable resources, and this leads to the disappointment of society and to a lack of belief in scientists.

A new social contract between society and the scientific community should be declared and established. This new partnership should be established between natural scientists, ethicists (environmentalists), social scientists and economists, technologists, government, academia and the private sector.

Scientists have a role to play in identifying the key issues but also in listening to the concerns of the policy community. A proper balance between the interests of the private sector and national goals should always be maintained through permanent dissemination of objective, scientifically based information.

There was a very intensive discussion in relation to policy-making decisions. Today, a quite noticeable gap exists between the sum of scientific results and the level of political decisions. To serve policy-makers, first scientific knowledge should be adjusted to the political level and, second, politicians should listen to the objective recommendations of the scientific community. Comprehensive national and international assessments are critical tools in assessing knowledge, including uncertainties in science and economic information that is policy relevant and policy neutral as a basis for policy decision-making. Assessments must evaluate historical and cultural trends, current conditions and plausible futures of both the state of the environment and the underlying socio-economic context. Assessments include risk assessment and an evaluation of risk management options. Scientists should stimulate public debate on key issues to see the pros and cons based on full available information. Before taking a decision, all policy decision-makers should receive the best scientific, technical and economic information currently available and society should know about that.

In many cases, policy requires scientific facts; in many others it requires a scientific prediction based on a model of a complex system. Science is an important input to the process of making public policy but it does not produce policy prescriptions. One of the frameworks for policy-making is the hierarchy of several levels of issues called, in ascending order of difficulty, 'know what', 'know how', 'know when, where, who', 'know why' and 'know whether' issues. The input of science is at the first level; the succeeding levels relate to technology, experience, motivation and judgement – that last level representing the government decision which must also take into account ethical and moral issues, political considerations, any economic, social and environmental implications, predictable unintended consequences and events.

Of special importance are the strategy and tactics of policy-making decisions in cases of big national natural disasters – earthquake, flood, large fires, etc. The history of the 20th century unfortunately gives too many examples of occasions when basic and global political decisions have been taken by national powers and international communities without appropriate and adequate analysis – when and if we decide that, the consequences would be these, and if we decide differently the consequences would be those.

There should always be iterations to the right decision and feedback with analysis as to whether this really is a wise decision and, if not, what conclusions should be drawn.

The role of pseudo-science and false 'science' was discussed. The latter, including astrology, unidentified flying objects (UFOs), etc., has been elaborated too much in modern society. Non-scientific ideas and hypothesis should not be taken into consideration by decision-makers and one of the important duties of the scientific community is to show the uselessness and destructive nature of such approaches.

Sustainable consumption in Europe: visionary or illusory?

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Humans have evolved excellent physiological mechanisms to defend against body weight loss, but only weak mechanisms to defend against body weight gain when food is abundant. Such is the availability of food, energy and manufactured goods in many Western countries that humankind is faced for the first time in its history with a multitude of consumer products and a deficiency of mechanisms to defend against excessive consumption. One example is seen in the current epidemic of obesity.

Policy-makers and politicians have rarely entertained the concept of sustainable consumption. Sustainable consumption is central to sustainable development which is threatened when present actions sacrifice the ability of future generations to meet their needs, let alone their wants. Yet, citizens are encouraged to spend and enjoy the consequences. Anything less is seen as a threat to business and profitability. In the 15 European states, gross domestic product (GDP) in 1995 was 6 434 billion Ecu, which represented over 25% of the world's GDP for just 6% of its population. For each person, GDP increased by 11% between 1991 and 1995. It is no accident, therefore, that this examination of sustainable consumption has chosen to focus on Europe.

What drives consumption?

When considering consumption, scientists focus on resource use, economists focus on the generation of utility and anthropologists and sociologists on the social meanings of consumption. Scientists define consumption as 'the human transformation of materials and energy. Consumption is of concern to the extent that it makes the transformed materials or energy less available for future use, or negatively impacts biophysical systems in such a way as to threaten human health, welfare or other things people value' (Anon., 1997).

Consumption has been attributed to population growth, but one of several available examples shows that this explanation is simplistic. The population of Bangladesh is increasing by about 2.4 million per year, while that of Britain is increasing by about 100 000 per year. Yet, because carbon dioxide (CO_2) emissions per person in Britain are 50 times higher than in Bangladesh, the 100 000 additional people in Britain cause more than double the CO_2 emissions of the 2.4 million extra people in Bangladesh.

Population size, however, is highly pertinent. If China or India reached an economic level comparable to that of more developed countries, as is their right, the impact on global supplies would be unsustainable. Clearly, the impact of consumption depends not on a single factor but on complex interactions between population, economic activity, technology choices, social values, institutions and policies.

Doing more with less through S&T

To do more with less is one way to move towards sustainable consumption. Novel ways to improve the capture and utilization of solar energy, efficiency gains in resource use, the invention of new materials with better prospects for reuse and the development of clean technologies are some of the challenges for science and technology.

Food

Concerning the use of solar energy, the Malthusian prognosis about population outrunning food output on a global scale has not been realized principally because the application of science and technology has provided new ways to increase production. Plant breeding is one of many examples that show a striking increase in performance far in excess of anything that could have been foreseen 200 years ago by Malthus. Gains in cereal production not least in Europe, one of the world's major grain producers, have progressed linearly over the last 50 years. The success of modern intensive agriculture, however, has occurred simultaneously with the loss of land to urbanization, and incurred soil degradation, erosion, desertification and a rising dependence on irrigation. The picture that emerges is one of unsustainable production.

Modern bioengineering is being used to develop high-yielding crops that can be grown in more efficient systems that require fewer chemical applications and produce lower levels of environmental pollutants. In Europe the successful adoption of these procedures is not yet assured. Ethical debates about safety, utility, fairness, naturalness, equity and the 'slippery slope' mean that, whereas Europe has invented and developed much of the science and many of the skills, it has yet to come to terms with the public acceptability of biotechnology.

Energy

Here again, as with food production, public confidence in scientific achievements is central to future success. Between 1960 and 1990 world energy use rose by about 3% per annum and the projection of the present trends suggests a doubling of total energy demand by about the year 2020. Yet the challenge of how to meet these demands is contentious.

Non-renewable fuels provide a major proportion of energy usage (in the EU for 1995: oil consumption 45%; coal and lignite 21%; nuclear power 14%; natural gas 18%). The supply will last for only a little over 100 years with today's technologies. Estimates of reserves have risen substantially owing to the discoveries of new deposits and improvements in mining technologies, and will last almost 600 years if likely recoverable reserves are included and almost 1 400 years with fast nuclear technology.

Renewable energy sources are attracting increased attention. At present they contribute only about 5% of consumed energy in the EU. In traditional agriculture they include fuelwood, crop residues and dung; in more advanced systems they involve hydroelectric schemes, solar energy, solar thermal power, solar photovoltaic power, wind power, biomass from non-food crops, tidal power, wave power and artificial photosynthesis. Together, they contribute 16% and 25%, respectively, to global energy use with biomass the leading new form and with the same favourable acid-gas and net CO_2 emissions as nuclear power.

The National Academies Policy Advisory Group concluded in its study on Energy and the Environment in the 21st Century (1995) that it was imperative to switch to renewable energy sources and nuclear power if consumption was to be limited to a sustainable level. Whereas public preferences clearly favour renewable energy sources, further development of nuclear programmes is controversial and has already been halted in Sweden and the Netherlands.

Materials

Materials science has become particularly fashionable in recent years. It provides a notable example of how new knowledge could contribute to the concept of sustainable consumption. The optimistic view is that engineering materials can contribute substantially to wealth creation (Kelly, 1998). Steel consumed per person either remains constant or more usually goes down as the income per person increases. This principle is true for many engineering materials (tin, rubber, plastics and silicon boules from which most computer chips are made), though not for commodities that are scarce or cannot be recycled. According to Kelly (1998) the explanation lies in the 'cleverness, skill and ingenuity of the engineers' concerned with production, fabrication of useful artefacts and their distribution to the consumer.

The pessimistic view is that, although new knowledge can assist sustainability, the materials-intensive model of extraction, processing and disposal provides more evidence that today's material flow is unsustainable. If the world's 6 billion people used materials as intensively as the average American, materials use would increase sixfold and environmental damage would rise similarly.

For all three areas – food, energy, materials – the vision exists that it is possible to do more with less through science and technology. This laudable aim lies at the centre of numerous international initiatives but danger lies in two areas – escalating levels of environmental damage and a lack of public confidence in novel scientific or technological advances, particularly in Europe. So is the concept of sustainable consumption illusory?

The role of policy

Politically inspired interventions that include such measures as price control to cap consumption would be seen as wholly unfeasible by most conventionally minded policy-makers and politicians. The need to reduce consumption, however, has been the mantra of the 'deep' Green movement for years. The solution proposed by Myers (1997) is a radical and controversial five-point plan: expand eco-technologies (world market worth US$ 600 billion per annum); get the prices right (gasoline/petrol); change gross national product as an economic indicator for an environmentally sensitive index such as net national product; reform the tax system; and get rid of perverse subsidies.

The role of consumer behaviour

Little support will be gained for the concept of sustainable consumption unless policy-makers and politicians are persuaded that it would lead to an improvement in the quality of life or that changes in consumer behaviour would make a difference. Quantitative measurements of the impacts of current consumption patterns are required so that the benefits of changing consumption could be monitored and benchmarked. In the UK, a recent analysis has shown that much of the expenditure increase of the past 40 years related to environmental and non-material needs rather than material needs. This would imply that the behaviour of consumers is susceptible to change at least in the non-material sector of expenditure. The task of changing consumption behaviour will demand greater communication between natural scientists and economists – they will need to take each other more seriously!

An informal network of the world's academies, the InterAcademy Panel on International Issues (IAP), will address the subject of Transition to Sustainability at its meeting in Tokyo in May 2000. One of the themes will be sustainable consumption (see www.national-academies.org/iap).

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World population growth: issues and policy implications of demographic changes

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The Population Summit of the world's scientific academies, held in New Delhi, India, in 1993, unambigously stated that 'The world is in the midst of an unprecedented expansion of human numbers'. And that 'We face the prospect of a further doubling of the population within the next half century. Most of this growth will take place in developing countries'.

There are already unmistakable indications of the severe environmental stress resulting in growing loss of biodiversity, increasing greenhouse gas emissions, stratospheric ozone depletion, diminishing forest cover, loss of top soil and shortage of water, food and fuel-wood in many parts of the world.

Current demographic scenario and future projections

Much has already been written on the subject and does not need to be repeated. To act as a timely reminder, only a few major facts are reiterated. The date of 12 October 1999 will be observed as the day world population exceeds 6 billion (UNFPA announcement). Currently, more than 80 million people each year are being added to this number.

The world population increase is now 1.5% (down from 2% in 1970) and is projected to be 1.3% in 2000-2010 and 1.1% in the next decade. If the growth rate does not fall further, world population will no doubt double by 2040.

There are, however, some hopeful signs. There is a much better understanding of the major determinants of this unabated growth, at least some of which are amenable to control, given political will and an effective executive machinery. These are as follows (not in any order of priority):

- poverty;
- illiteracy, especially among women;
- status of approachable and affordable health-care delivery, with special emphasis on reproductive health and the needs of women and children;
- availability of culturally sensitive, safe, user-friendly, affordable contraceptives, both for males and females;
- strict enforcement of laws governing the minimum age for marriage;
- employment opportunities for women.

According to Nafis Sadik, Secretary-General of the United Nations Population Fund (UNFPA), 'fertility and family size have fallen faster than ever before. The momentum of population growth has slowed, is slowing and will slow further'. Thus, according to United Nations projections, over the next few decades, fertility will reach replacement level (2.1 births per woman) in both the developed and developing countries and will remain at that level after 2050.

Demographic implications of the current population scenario

Much of the developing world is now well into a transition from high fertility and mortality rates to low ones. The world is both younger and older than ever before. Today, half the population in developing countries is under 23 years old. By 2000 an estimated 800 million people – 15% of the world's population – will be teenagers. This results in a 'demographic momentum' implying that even after the fertility rate falls below replacement level, the population will continue to increase for several decades thereafter.

At the other end of the scale, in most developed countries there are increasing numbers of ageing people. It is estimated that, by 2010, 30% of the population in Japan, 25%

in Italy and Germany, 23% in the UK and France and 20% in the USA, Canada and Russia will be over the age of 60.

An ageing population implies an increasing socio-economic burden on the young earning members of the society and the state. In addition, it adds to the national pool of chronic debilitating diseases like cardiac and cerebrovascular disorders, degenerative arthritis, osteoporosis, dementias, Parkinson's disease, cancer, etc., which add to the already rising cost of health care globally. According to Peter Peterson, a distinguished Wall Street personality, 'the dollar cost of the age-wave works out to a minimum of US$ 64 trillion, a mind-boggling number that could destroy the finances of many countries and trigger an economic crisis...'.

Another impact of the current demographic situation, especially in developing countries, is rural-urban migration, creation of urban slums, straining the already precarious civic support systems – water supply, waste disposal, housing, transportation, health care.

The 1994 *World Economic and Social Survey* pointed out that 'in the next 35 years (1990-2025) it is not the number of people on earth, but rather their production and consumption patterns that will determine the level of environmental degradation…'.

Current bottlenecks in implementation of population policy

Population policy is not only about fertility regulation. Fertility is only one parameter that requires sensitive management to which the scientific and technological (S&T) community can contribute a great deal. As mentioned earlier, a whole lot of other factors need to be addressed, such as poverty alleviation, education especially of the girl child, socio-economic empowerment of women, environmental protection, migration and urbanization, provision of food, water, shelter and employment. These problems are tightly intertwined. Each one can be both the cause and the consequence of population growth. They can neither be examined nor resolved separately.

As a result of national and international efforts, there is a far greater appreciation of the need for and acceptance of the small family size norm even among the developing countries. According to a report by the Institute of Medicine, an arm of the US National Academy of Science, 'Were only unwanted births prevented, the global number of live births would fall from 139 million a year to 122 million and the global rate of population growth would drop by 19%.' Despite a progressive increase in contraceptive use worldwide, the 'unmet need' for family planning is estimated to be at least 120 million and probably much more.

At a recent review of the International Conference on Population and Development (ICPD) Programme of Action, held in The Hague earlier this year, Dr Nafis Sadiq accepted that, not withstanding perceptible gains, there remain a number of obstacles and challenges to implementing the programme outlined in Cairo, Egypt, in 1994. Among other things an obvious one was provision of contraceptives.

Simply making contraceptives available to those who want to use them should be a very practical way to at least partly control the continued increase in world population. What then are the impediments? One, no doubt, is paucity of available resources. Lester Brown, President of the World Watch Institute, estimated the requirements for implementing the ICPD Programme of Action to be around US$ 1.3 billion.

The other aspect of this problem concerns research and development (R&D) efforts required for developing newer, safer, more acceptable, user-friendly, cost-effective contraceptives both for males and females, as was unambiguously highlighted at the Population Summit. The need for renewed efforts in this direction has recently been critically discussed in the 1996 Institute of Medicine monograph, *Contraceptive Research and Development: Looking to the Future.*

The available contraceptive array is limited in the extent to which it can respond to variability in individual and family situations, to cultural differences, to specific health problems and shifting personal preferences and to life-cycle stages and changing reproductive intentions across these stages. There is an additional need for contraceptives which can also be protective against sexually transmitted diseases, especially HIV. Lest it be misunderstood, contraceptives should not be assumed to be the only or even the most important method of fertility control. Contraception has to be integrated with overall reproductive and other health services.

Unfortunately, in spite of repeated reiteration of the need for such efforts and the excellent opportunities provided by new biology, combinatorial chemistry and polymer science, there is little evidence to suggest that enough attention is being paid to this field by global S&T or by industry or by international agencies. A survey of funding for contraceptive R&D over the past 15 years indicates that it has at best remained the same in constant dollar terms and may actually have diminished.

What can S&T do?

It is obvious that, to meet the challenges of population growth, there is an urgent need for a collaborative effort between the

S&T community of both the developing and developed countries and industry supported by national governments and international agencies. This calls for an innovative policy paradigm which would aim at developing and providing a battery of contraceptives to satisfy the special needs of different population groups at an affordable price and yet satisfy the reasonable profit needs of the industry.

The S&T community is fully aware that provision of contraceptives is just one of the many measures necessary to control fertility. As mentioned earlier poverty eradication, education, provision of nutrition, safe drinking water, health care services, information dissemination, employment generation – in short development itself, results in fertility control directly or indirectly. Scientists, engineers and health professionals can contribute immensely in each one of these spheres.

At the same time, it must also be recognized that our ultimate concern (i.e. sustainable development of our planet) is not only threatened by growing numbers but also by the production and consumption patterns of the already developed world, which the increasing numbers in the developing countries would tend to imitate. This is going to be the subject of a separate presentation at this conference. I would only like to conclude by recalling that the intensive efforts initiated more than three decades ago to control population growth, which have now started to show some positive effects, are so far not visible on the other front.

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Science, a learning model for development

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Development of societies entails an absolute prerequisite, often forgotten, which is the intellectual and moral development of Man, the contribution of science being essential here. Indeed, science is tirelessly educating us, certainly addressing our knowledge and intelligence, but also both our personal and social behaviour. What does this instruction teach us? What does it tell, especially, those – in fact the majority – who are not destined for science?

The idea of truth

Science certainly does not teach us the truth. Science does, however, at least tell us that there is truth buried away there in the universe, revealed at minimum by the effects, laws or theorems it teaches us against some fashionable scepticism or ancestral beliefs. Humanity cannot develop if it does not learn to introduce into its vision of the world this idea of truth, a truth conceived as fundamentally polyphonic, including harmonics (poetic, religious, artistic or philosophical) other than scientific.

Humility

With Galileo, science became humble in that Man decided to seek the answer to his questions at the very heart of Mother Nature – by questioning her through experimentation – rather than from the subtle depths of his own thought. This modesty is one of the hidden forces (generally we celebrate more its power than its efficiency!) that drive development; it is by patient observation of Nature and the ways in which she functions that humans can sharpen their own creativity and invent objects, devise processes, elaborate structures – in both the physical and intellectual sense – able to operate in favour of development.

The spirit of research

By unveiling some of the laws that govern Nature, our learning of the sciences reveals to us the immensity of what we do not know. They teach us therefore to say ‘I don’t know’, which generates the spirit of research and thus the taste for undertaking it and, therefore, the ability to progress. In this way, science is indubitably a space which is a privileged theatre for imagination and liberty, although not the only one.

The spirit of freedom

If science is a space for freedom, then it constitutes a humus for development. How would this be possible in the long term in a society that would keep Man confined by prohibitions of his thought, speech, writings, or liberty to circulate or publish? Science, through its history and its practice, teaches us liberty. This spirit of freedom establishes the two major prerequisites for development which are human creativity and the dignity of societies. Therein lie undoubtedly the two ingredients crucial for a kind of development which will be sustainable and will escape the deadly hold of dictatorships of all kinds, as well as specious illusions of easy money and financial adventures.

Conclusion

In the deep complicity shown in the spirits of truth, humility, creation and freedom, science shows itself to be a powerful factor of human growth and maturation, an essential prerequisite – well upstream of innumerable applications and inventions, industries and techniques that it gives rise to – for a smooth, steady development of populations and societies.

Food in transition to sustainability

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The Director General of the Food and Agriculture Organization of the United Nations (FAO) stated in his message to the 1996 Rome World Food Summit on *The Right to Food*: 'The right to food is the most fundamental of human rights. Alongside peace, hunger is the most pressing of all issues. There must be two principal components in any strategy to eradicate hunger. One is to produce enough food. The second is the political will to ensure that all people have access to food for a healthy life. Currently 800 million people are chronically undernourished. Some 190 million children under the age of five suffer from acute or chronic protein and energy deficiencies.

'The basic goal of universal food security (i.e. i) the availability of food supply; ii) the stability of food supply; and iii) the access to food) is one that peoples, governments and the international community, including the international scientific, engineering and technological community, have no alternative but to address.'

In other words, we must all join forces to meet one of the greatest challenges to a sustainable world, the challenge of universal food security. Over the next 50 years, worldwide demand for food is expected to triple in response to population growth, growth of per capita income and continuing attempts to reduce under-nutrition of the poor.

During the last half-century, gains in crop production have come from four interrelated sources:

- expansion of cultivated land;
- increased use of fertilizer and pest control chemicals;
- expansion of irrigated area;
- introduction of high-yielding varieties.

However, continued gains in agricultural production required in the 21st century will be considerably more difficult to accomplish than in the immediate past.

It is said that current world food production has practically reached a plateau. Some 10 million hectares of agricultural land become degraded and unproductive annually and must be replaced. An additional 5 million hectares must be converted to agricultural uses to supply food. Essentially all of the land is obtained by deforestation. This is clearly unsustainable. The present methods of intensive agriculture are limited by factors such as water supply, soil depletion, the increasingly large amount of energy required per unit of food and losses during transportation and storage.

As for fisheries and aquaculture, the 1998 FAO *Report on the State of World Fisheries and Aquaculture* states: 'Supplies for human consumption increased considerably in the two years 1995-96, rising from 14.3 kg (kilograms) per caput (live weight equivalent) in 1994 to 15.7 kg in 1996. Yet if the rapid increase of production in China is excluded, the average food fish supply for the world in 1996 remained close to the level recorded during the first half of the 1990s and was somewhat lower than that of the 1980s.'

The report gave a cautiously optimistic forecast of total fish supplies in the first decade of the 21st century of 135 million tonnes per annum, adequate for satisfying demand on the assumption that the current economic crisis which dampens demand will continue into the next century and will also affect the more developed countries. The forecast did not take account of the impact of biotechnology on aquaculture. Already genetic improvements in salmon, tilapia, carp and oysters have been successful in raising production.

In agriculture, biotechnology also holds substantial hope for the improvement of crop production, reduction in the use of chemicals for disease and pest control and better efficiency of resource use. Scientific and technological breakthroughs, particularly biotechnology, could over the medium and long term lead to a lifting of the yield ceilings that have been set by Green Revolution technologies.

Biotechnology will also feature prominently in the closely related problem of water scarcity. The Panel on Biotechnology of the World Commission on Water for the 21st Century issued a report on *Biotechnology and Water Security in the 21st Century* in February 1999 after the meeting in the M.S. Swaminathan Research Foundation, Chennai, India.

The report states that recent advances in biotechnology have opened up a big potential to save water, principally by reducing the water consumption of plants and by treating wastewater. Within the next decade, the functions of most of the genes that are in a plant will most likely be known. These scientific advances will allow the engineering of desirable traits into favourite species, i.e. species that are less thirsty, more tolerant to salinity and generally more water-stress resistant. Similarly, biotechnology, including simple cell protein (SCP) technology, will offer the possibility of ensuring clearer water. Biotechnology has the potential to purify water for reuse in high-value urban agriculture and other human use.

To me, it is quite apparent that, as far as the scientific, engineering and technological community is concerned, biotechnology will be key to meeting the challenge of universal food security. Yet, in the Rome *Declaration on World Food Security* and the *World Food Summit Plan of Action* of November 1996, application of biotechnology is mentioned almost in passing. Much emphasis is laid on local agricultural research capacity enhancement; local public and private capacity to make knowledge, technology and materials available to food producers; the schooling or informal education of farmers and farm workers, particularly women; regional and international cooperation in research and development and in technology transfer. Governments are requested to have the collective political will to avoid civil strife; to have plans to mitigate the effects of natural disasters; to foster stable and democratic government with good governance; and fair and equitable trade in food products.

I am not sure whether we can put in place such a global political and economic framework, however desirable, to achieve the target to reduce the number of undernourished people to half their present level by 2015. The ongoing events in the Balkans do not hold out much hope, even without taking into account the long-standing human tragedies in Africa or the trade-off in diplomacy and food in the Democratic People’s Republic of Korea.

Were the 175 member countries of FAO intentionally ignoring biotechnology as a political hot potato especially in this era of small government and free market enterprise?

I attended the discussion meeting on Science and Technology and Social Responsibility of the Royal Society of London on 16 March 1999. I applauded warmly the initiative of the Royal Society to invite speakers from the UK Consumers’ Association, Greenpeace and Friends of the Earth, as dialogue involving the whole spectrum of society was central to the theme of the discussion meeting. Unfortunately, the debate was too focused on genetically modified (GM) food, revealing to me that the divide between science and society was and must still be an unbridgeable chasm, at least in the UK.

On the one side, some prominent scientists held fast to their conviction that scientists must be free to pursue scientific research and enquiry unfettered by constraints on social and ethical grounds. Scientific discoveries were free from sin. Their conversion into technologies with any harmful consequences was the responsibility of the technologists and their corporations.

On the other side, it was equally firmly held that GM food and its technology should be banned. When I posed the question about the pressing need for food in the developing world, I was told in no uncertain terms that there is enough food being produced for all the world’s population. The problem is food distribution, i.e. political, economic and trade-related problems. To me, this is analogous to saying there is enough wealth in the world. The problem is merely wealth distribution. If only the rich will give some of their wealth away to the poor!

In May this year, I attended the Convocation of the Council of Academies of Engineering and Technological Sciences in Sophia Antipolis, France, with the theme Technology and Health. Once again, there was debate on genetically engineered ‘functional foods’. Only this time, concern was expressed by fellow scientists and engineers.

On transit in London after the convocation, I found Prince Charles prominently featured on the front page of the *Daily Mail* with his article on his fears over the safety of GM foods. He posed several questions. To me, they summarize quite well all the societal doubts and fears in the UK. He questioned the need for GM food in the UK. I agree with him. Why is there any such need? He conceded that, as yet, there is no evidence that GM food is not safe to eat but, he added, who knows in the future?

On the argument that GM food is needed to feed the world’s growing population, the Prince said this argument sounded suspiciously like emotional blackmail. The countries which might be expected to benefit most take a different view. Representatives of 20 African states, including Ethiopia, have published a statement denying that gene technologies will help farmers to produce the food that is needed in the 21st century. The Prince asserted further that GM food would lead to industrialized agriculture being dominated by a few giant multinational corporations throwing millions of farmers out of their means of livelihood.

To me, the above argument ignores the fact that raising food production by biotechnology is not restricted to state-of-the-art laboratories in developed countries. Less developed countries with large populations like China and India have already been making a most dramatic increase in rice and wheat production using biotechnology in their own research institutions. What is more, the research is mainly public-sector funded.

There are also many people concerned over GM food in developing countries, scientists and engineers included. We should not use a statement by certain representatives from 20 African states or elsewhere as conclusive evidence and going on public record that there is no need for biotechnology to increase food supply in those countries.

On the Prince's plea for independent scientific research over the long term, I would like to pose the question to fellow academies of sciences and academies of social sciences, particularly in developed countries, of whether they can assume the important role of independent and transparent monitors or referees on the use of biotechnology in food. Academies of sciences and academies of social sciences are very proud of the fact that they are independent of government and vested interests.

In view of the cancer scare of dioxin contamination in animal feed in Belgium and the BSE or 'mad cow disease' in the UK, the chicken flu in Hong Kong and the Nipah virus affecting pigs in Malaysia, I am also in agreement with the Prince's argument for more stringent control and testing of GM food and its related food production chain. FAO is hard at work on a code of practice for good animal feeding. Again, the academies of sciences can play an important review and monitoring role in view of their independence from government, politics and commercial interests.

As a professional electrical power engineer, I have been bound by a code of practice whose first tenet is that public interest and safety is paramount. I would be struck off should I ever violate that tenet. I think it is time that bioscientists and biotechnologists are bound by a code of practice and are licensed by professional boards with enforcement powers to ensure their professional practice is within the framework of public good and safety. Again, I see academies of sciences having an important role in this initiative.

I would like to come back to the theme of this session, Joining Forces for a Sustainable World. I think everyone is agreed that the elimination of poverty and hunger is a prerequisite for a sustainable world. Currently there is a controversy raging on the use of biotechnology in food production. We must all get together to have meaningful and rational dialogue. Again, isn't it the role of the academies of sciences and academies of social sciences to bring this about?

Finally, may I offer as a basis for rational dialogue the abstract of the speech of one of the speakers in the above-mentioned discussion meeting of the Royal Society:

'In all societies, crops are grown to provide human food, feed for animals, construction materials and feed stocks for many industries, large and small. The diversity of species, genetic variants within each species and agricultural systems used around the world is enormous. This diversity has emerged over the thousands of years of experimentation, innovation and a vast number of consumer-led choices. Genetic diversity from natural variation or from man's intervention via plant breeding has been a key.

'The introduction of genetically modified crops into agriculture provides yet another example of where recent scientific and technological advances (also the speed of such advances) make it difficult for the consumer to be well informed, to be confident about the technology and to trust politicians, expert groups and companies who all too often appear to be promoting departures from tried and trusted principles and practice. Most often concerns over the scientific process and genes are mixed up with concerns over how the crops will be marketed, who will win the economic returns and whether consumers will lose choice. Benefits versus perceived risks are rarely debated accurately.

'The responsibilities of scientists to communicate understanding of the technology are obvious but the means of doing so effectively are far from straight-forward, especially when non-scientific arguments are the origins of the unease.'

International health: changing patterns and policy implications

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Ever since the 1950s, there has been a pronounced improvement in health on a global scale. This is reflected in the markedly increased average lifespan. However, the developments in health, paralleling the accumulation of wealth, are distributed in a highly uneven way. When it comes to resources, the gap between industrialized and developing countries seems to widen with time. A number of evolving problems are of critical significance to the diverging global health problems. Examples are population dynamics, accentuated urbanization, environmental threats and food and water supply.

Presently there is a major difference between the disease panorama in industrialized and developing countries.

Infectious diseases with involvement of the respiratory or enteric tract dominate, together with parasitic diseases in developing countries. In addition, there are conditions arising during the perinatal period which may have dire consequences for both mother and child. Most likely, the impact of such predominantly infectious diseases will be reduced with time. Effective development of vaccines, in some cases applied for complete eradication of diseases, as well as antimicrobial agents, including new drugs to circumvent problems of drug resistance, will influence this development. Progressively, the disease panorama of industrialized and developing countries will become more similar. In parallel, there will be development in the former countries of a more effective handling of non-communicable diseases. New techniques and materials will have a major impact, and conditions for providing organic spare parts may improve much through development of stem cell techniques in addition to the conventional use of organs or bone marrow cells. However, the major impact will come through new advances in molecular genetics drastically expanding the field of molecular medicine.

Sustainability: Central and Eastern European aspects

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In the past decade, sustainable development has become a popular concept all over the world including in the former Soviet Union and its satellites. To meet the increasing needs of the society of today, without compromising the ability of future generations to satisfy their own aspirations, is a very promising goal. However, sustainability assumes a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, institutional as well as other societal changes, should be in harmony, which is anything but typical in these countries. Ten years after the political collapse of the system, the new societies in transition face formidable difficulties both in catching up with industrialized nations and in finding sustainable means for this evolution process. In the following we give a brief overview of some special features of sustainability in the Central and Eastern European region.

In order to understand the basis of difficulties influencing development we must be aware of the extreme rigidity of the former Soviet system, which was loosened gradually after Stalin’s death in Central European countries and to a much lesser degree in the Asian republics. However, human rights, free access to information, creativity and responsibility were in all times insufficient, and even now we have a deficit of these spiritual goods. There was a reduced and often politically suppressed interest in environmental issues and the centrally planned demand for more industrial goods led to the establishment of polluting industries, transport and agriculture. Consequently, resources were overexploited, leading for example to the failing performance of the oil industry in the 1980s or gradual deforestation of the mountains, which in turn led to increased danger of floods, as well as soil degradation in agricultural regions. Large deposits of toxic and radioactive wastes were formed; modern methods for regeneration or safe reprocessing, as well as the necessary financial means, were often completely absent. Quality was a less important, often negligible, factor ranking much behind quantity.

As a result of the above problems, economies could not catch up with those of the industrialized nations, although the region cannot be considered as a homogeneous, faceless entity. The best performance is provided by the vanguards, countries that were components of the Austro-Hungarian empire or the Baltic region. Here macroeconomic indicators are quite good with growth figures doubling that of the European Union (EU) (4-6% in 1998 as compared to around 2.5% in the EU). Inflation is decreasing, legislation and progress in privatization are about to catch up with European standards; furthermore the performance of small and medium-sized enterprises is acceptable. The losers belong to the less-developed regions of the former Soviet Union and are politically unstable with severe economic depression and often social unrest. Countries between vanguards and losers, mostly also in the geographical sense, have some hope of catching up but, certainly, this is not possible without robust outside financial and political support. Industrialized nations must provide this support because, in the absence of any hope of development, the increasing political, social and economic differences will certainly lead to local, even regional, crises as in Kosovo or in Chechnya. Sustainable development of the West (or the North) is not feasible without its support to the East (the South).

A special feature of the European countries in transition is that there is no danger of population explosion, rather a slight (in some countries larger) decrease in birth rates can be observed, which is in line with the trends in Western Europe. Since mortality is high, the population is slowly but steadily decreasing, which provides, however, an imbalance, with an increased flow of migrants to the more developed regions from the less developed ones, and political, social and cultural tensions. This might be dangerous, since the social capital (health state, social mobility and solidarity, education, cultural diversity and similar issues) is diminishing, which makes these societies especially vulnerable to any challenges. All over Central and Eastern Europe, society is suffering from the increasing gap between the rich and poor and many experts state that this is the ultimate basis of growing crime figures, extended alcoholism and drug abuse, as well as high mortality. Fortunately, outside Moscow (9 million inhabitants), St Petersburg (5 million) and Kiev (3 million), there seems to be no danger of unhealthy concentration of the population as in the Third World, though the infrastructure and other conditions are not fully appropriate in these urban areas.

Although, in the next decades, population will not increase considerably in Central and Eastern Europe, the drive for higher consumption is extraordinary. All citizens have become targets of massive advertising campaigns, mostly engineered by multinational companies settled in the region. This effect, combined with the lag behind industrialized nations, makes people consume more. Since there are no reasonable arguments for moderation of the need for physical goods, the public does not understand the very essence of sustainable consumption. Prestige consumption may become extraordinary and everybody will strive to project an image of having more than he/she does have in reality.

There seems to be enough food in the region; intensification of agriculture may, and in fact does, assure self-sufficiency even if Russian grain imports are extremely high. There are no signs of large-scale starvation, even if local wars may lead to serious shortages. While the quantity of food is satisfactory, its quality should be considerably improved. Fat and other cholesterol contents are usually high, while vitamins are mostly absent; there is no sufficient and generally available information on the ingredients of marketed food. There is no drive, nor financial means that may help to switch to healthier nutrition. Housing satisfies elementary needs; however, the quality of shelter is not always satisfactory. More care should be taken to reduce energy use and install appropriate canalization. Homeless people have appeared everywhere in larger cities; they are mostly alcoholics and are quite often infected by diseases, such as AIDS and tuberculosis, that pose a health risk for the public. Fortunately, several charities have appeared and taken over some of the burden from overloaded authorities. Again, the situation is better in vanguard countries than in losers, where it is sometimes dangerous even to perform social work.

Health problems are numerous in Central and Eastern Europe. As already mentioned, life expectancy is lower here than in industrialized countries; the difference exceeds 10 years in some regions. The health care system is failing; necessary reforms, in fact reductions in the role of the state, are not accepted by the public. Here again, the need for consumption is increasing fast, which means that everybody will have access to modern, most expensive chemical and instrumental diagnostic systems and the highest-level health care. The costs are immense and steadily increasing; state administrations have no clear vision of a sustainable health care model. A special problem in Hungary, for example, is the increased inclination to multiply pharmaceuticals by the average patient that is leading to an exponential growth in costs which cannot be absorbed either by the state budget or the patient.

The above outline seems to be rather pessimistic; the transition to sustainability will not be easy in Central and Eastern Europe, especially in loser countries. However, we have reason for moderate optimism because the education system is good, especially in Central Europe, providing more than a dozen Nobel Laureates in the 20th century. Environmental issues are receiving more and more attention from the young generation; several actions have been organized with success and devotion. For the young a new paradigm seems to be developing, where the state of the environment and a modest, stress-free lifestyle are more important than prestige consumption. Transition to sustainability is certainly realistic in this region, even if possibly at a slower rate than in Western Europe. It is therefore very important that rich countries play the role of spiritual and institutional leaders by inventing appropriate behavioural patterns and providing financial means, as well as doing extensive scientific research. This is how we may lay the foundations of a sustainable global world we would like to face in the 21st century.

Thematic meeting report

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The world's academies of sciences have begun a collaborative effort to explore the challenges and opportunities for a global transition to sustainability in the 21st century, leading to a conference and action agenda in May 2000. Academies of science, social science, medicine and engineering, as well as other non-governmental organizations, must join forces for a sustainable world.

- One of the recurrent themes of the 21st century will be to understand better the drivers of consumption patterns, the underlying behavioural mechanisms and how resource consumption can become more efficient. The drivers of consumption are complex and do not depend on a single factor but on a range of components including population, economic activity, technology choices, social values, institutions and policies.
- There are encouraging trends of falling human fertility and smaller family size from most countries of the world. However, an important question still remains as to whether the global population will stabilize in time to prevent irreversible damage to the global ecosystem. Policy issues of current demographic trends include the increasing number of poor young people in developing countries and the medical and socio-economic burden of the ageing population in the developed nations.
- Education which teaches the values of science is critical for meeting the challenges of a sustainable world. These values include: the idea of truth, humility, the spirit of research and the spirit of freedom. Human creativity and the dignity of societies are two ingredients crucial for sustainable development.
- Over the next 50 years, worldwide demand for food is expected to triple. The challenge of meeting this demand requires dramatic advances in food production and distribution, and in food security. To sustain growth in agricultural production, new knowledge and information systems will be required.
- Since the 1950s, there has been a pronounced improvement in health on a global scale, which is reflected in the markedly increased average lifespan. However, the developments in health, paralleling the accumulation of wealth, are distributed in an uneven way. Evolving problems of critical significance to diverging global health are population dynamics, accentuated urbanization, environmental threats, and food and water supply.
- The countries of Central and Eastern Europe are in transition from centrally managed to market economies, which require use of science and technology for more efficient use of resources and a reduced environmental impact in meeting new consumer demands for products and services.

Science in totalitarian and post-totalitarian regimes

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The following talk by a social, rather than by a natural, scientist is not concerned with, say, the rejection of the theory of relativity by so-called 'Aryan' physics during the Nazi dictatorship or with what Lysenko, supported by Stalin, for a time did to biological theory and research in the Soviet Union. Rather, my talk will be about the role of political science in pre-1945 Nazi Germany and in the post-1945 German Democratic Republic (GDR). (Let me add, as an aside: I am not certain that the term 'totalitarian' fits both regimes or every period of their existence. However, I cannot go into that here.) Anyway, I hope to show that both regimes had some use for political science and that this fact leaves us with a few rather sobering questions about the seductive chances offered by totalitarian systems, about scholars and ideologues, and about the interactions of both.

Beginnings of political science had existed in Germany during the Weimar Republic, with a foothold in a few universities (such as Hamburg, Leipzig or Heidelberg), but mainly extramurally, at the Berlin Institute of Politics. After 1933, those scholars who were either Jewish or convinced democrats, or both, were quickly forced into exile. The discipline was emasculated: everything was dropped from teaching and research that had to do either with domestic politics or with normative considerations about a polity founded on principles other than those espoused by the Nazi Party. Political science – limited to, and accordingly rechristened, *Auslandskunde* or Foreign Studies – was left with two tasks:

- Before 1939/1940, it was supposed (in the jargon of that era) to 'reconnoitre for the Reich', to study those – foremost European – countries and their political systems in which the regime was primarily interested for purposes of cooperation or conquest. Consequently, empirical analyses continued to appear and political scientists formerly adverse to the Weimar Republic were, in many instances, prepared to collaborate, to the extent of contributing to the tasks of the SS-led *Reichssicherheitshauptamt* or Reich Main Security Office.
- After 1940, the politicized discipline's mission increasingly consisted in contributing to the ideology of a supposedly 'New Order' in Europe, to be built by the German Reich as a fortress against bolshevism. In a nutshell, that meant attempting to legitimize relations between the conquered regions of Europe and Germany not built on equity principles, but rather on spoliation, slave labour and racist extermination policies.

In the GDR, established by 1949, the ruling party was confident that its policies were governed by immutable laws of history, discovered and described by Marx, amended and partially revised by Lenin and Stalin, later by successive Communist Party conferences. Such a ruling party might require, for educational purposes (shaping the new 'Socialist personality'), a discipline of 'Scientific Communism' teaching dialectical and historical materialism, political economy, development of the Communist Movement. What it did precisely not need was political science – except as a smokescreen providing for academic recognition, after the International Political Science Association (IPSA) had been founded in 1949. GDR scholars travelling to IPSA World Congresses left as philosophers, historians or political economists, arrived as political scientists and returned home again in their former capacity.

The arrangement more or less satisfied everybody as a contribution to 'peaceful coexistence'. When, however, after the collapse of the GDR, the proponents of Scientific Communism attempted to actually mutate into political scientists, the attempt foundered badly. West German scholars were recruited to introduce political science, as it had evolved in West Germany, into former GDR universities – a process generating not a few problems of its own, as might be guessed.

In both Nazi Germany and the GDR, distinctions became blurred, in the social sciences, between scholars and ideologues. The GDR had very little to offer to political scientists. Nazi Germany held attractions for not a few scholars – in the social but also, of course, in engineering and the natural sciences. One instance of the latter must suffice here in order to illustrate a final point.

Research by Michael Neufeld in Washington DC and by myself conclusively proves that Wernher von Braun – the Peenemünde engineer who was later acclaimed as 'the free world's leading space travel authority' and who, with his collaborators, built the V-2 guided missile – not only became an SS officer in 1940, not only profited from the slave labour of concentration camp inmates who mass-produced the rocket, but in 1944 personally went to Buchenwald concentration camp to select professionally versed inmates.

After 1945, von Braun and other engineers lied and dissembled, claiming that Peenemünde on the Baltic Sea had been a pure researchers' world, separate and far apart not merely in geographical terms from the slave state for which only the SS was asserted to bear responsibility. In reality, however, Peenemünde – like every such social or natural science institution – was profoundly enmeshed with the regime's inhuman policies. The existence of two separate worlds under totalitarianism, a scientific domain and a garrison state, was and remains a myth, a legend – an illusion.

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The idea of the university in a democratic society

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The university is a social institution in the context of which the relationship between science and democracy can fruitfully be examined. It exemplifies well the ambivalence of the relationship, incorporating both a number of democratic principles but also some counter-democratic premises. Science is facilitated by the democratic political context, because democracy safeguards two core demands of science: academic autonomy and intellectual freedom. It is only in a democratic society that the scientific community may be self-governing and self-policing, and that the open expression of all contesting views coupled with uncompromising debate and critique can be fully assured. The 'republic of scholars' and the 'community of teachers and pupils' can flourish only within the democratic polity. But at the same time it cannot be lost from view that the university is a very particular republic and a very unusual community.

Democracy may endanger science when it questions and undermines the very uniqueness of scientific enterprise: the intrinsic elitism of science as a field accessible only to the talented few, the necessary hierarchy of academic status based on meritocratic achievement and the recognition of expertise and competence in making claims to knowledge. The abuse and misapplication of democratic, and especially liberal democratic, ideas with respect to science may accordingly take three forms: the lowering of criteria of recruitment in the name of universal access, flattening of academic hierarchy in the name of egalitarianism and uniformization of paradigms in the name of appeasing the majority. All three endanger the scientific goals of science and destroy the special status of the university among other social institutions.

Scientific autonomy and democratic debate

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The relationship between science and democracy has historically been a positive one, with mutual reinforcement because of the many analogies in terms of values and principles, norms and procedures, organizational patterns and social relations, which can be traced to the common heritage of modernity and modern culture. Differences also exist, insofar as the basic democratic principle of majority rule cannot apply to science, and scientific communities recognize and value hierarchies of excellence and prestige and tend to be elitist, whereas democracies uphold equality as a core principle. Another basic difference lies in the fact that democratic polities are still to a very large extent coincident with nation states, whereas scientific communities tend to be world communities transcending national boundaries. But analogies and affinities prevail to the effect that science and democracy reinforce each other.

On the one hand, in fact, the fundamental values of contemporary democratic polities – such as freedom of speech, individual rights, equal opportunities, public accountability and transparency, as well as the organizational patterns of self-government and representation, are to a great extent coherent with the basic principles of science and provide a context favourable to the free production, dissemination and usage of scientific knowledge. On the other hand, scientific research and scientific education contribute to the culture of democracy insofar as they educate citizens to think freely, accept competing alternative views, apply universalistic standards in selecting among competing viewpoints, weigh options on the basis of shared objective criteria, assess data, test political programmes in terms of policy effectiveness. Moreover, science operates according to a built-in mechanism of self-correction and self-criticism which is important in democratic institutions as well.

This mutually beneficial relationship between science and democracy does not mean that science can take place only in democracies. Authoritarian or totalitarian regimes can achieve scientific and technological results, at least in the natural sciences. But they do not respect the autonomy of the scientific enterprise and constantly threaten it with ideological constraints and political interferences.

Significant departures from this ideal model of scientific freedom also take place in contemporary democracies, which can be traced to government and business influences on research funding and interference in defining research objectives and in selecting researchers. And yet, on the whole, democracies are more respectful of the principles of academic freedom and scientific autonomy than any other type of political regime. And there is no doubt that the returns of scientific research for sustainable development, improvement of the quality of life and meaningful relations among individuals and groups are much greater in the presence of democratic institutions.

Current trends

Today, the mutually beneficial relationship between science and democracy is being affected by several current trends. Although not implying a radical transformation, these trends – which have been at work for quite a while – have recently accelerated and intensified to the point of making the relationship problematic. We are witnessing the paradoxical situation that both science and democracy are increasingly criticized and their relationship is increasingly strained precisely in those countries where scientific achievements are greater and democratic institutions more consolidated.

I will briefly discuss five major trends which affect the relationship between science and democracy and scientists' relations with their major stakeholders.

- The first trend concerns the role of scientists and the context of their activity and is the shift from the individual disinterested pursuit of knowledge to a complex system of knowledge organizations. This shift poses such questions as: to what extent can creativity develop within bureaucracies with routinized procedures and how far can innovation be managed and organized? Serendipity, as a basic feature of scientific research, can play a countervailing role to bureaucratization, but the tension between scientific autonomy and bureaucratic organization is real.
- The second shift concerns the role of democratic governments: they are tending to reduce their general support for science in favour of a more specific commitment to scientific projects with immediate technological and economic implications. This shift has implied a diminishing investment in basic research and in long-term projects with no evident short-term practical applications.
- The third trend concerns the attitude of business vis-à-vis science and, specifically, its increasing interest in scientific research and its technological applications as basic requirements for market competition. It raises the complex question of proprietary science and the contradiction between the claims to private exploitation of research results through patents and the principle of free access to scientific discoveries.
- The fourth trend has to do with both the nature of the decision-making process in science investment policies and the consequences of scientific activities. While consequences are becoming increasingly global, investment decisions in research and development are still mostly taken at nation-state or at the corporation level. This trend bears special problems for the Third World. The knowledge gap between developed and developing countries has been widening, also as a result of the third trend, i.e. the privatization of research results. The consequences of developed countries' science policies are increasingly global (and not always beneficial, as in the case of the weapons industry), but the international dissemination of scientific knowledge is constrained.
- The fifth trend concerns the general public and it lies in the growing gap between the scientific experts and the average citizen. The very scope and pace of scientific advancement implies a growing asymmetry between scientific knowledge and general knowledge. In their daily lives average citizens have to rely more and more on the judgement of experts and on the functioning of complex systems. Given the

increasing complexity and abstractness of much scientific knowledge, they have to trust science and technology and even make true 'acts of faith'. Their trust and faith are reinforced by positive subjective experiences – such as those stemming from medical advancements like organ transplants, or technological innovations bettering the quality of their life – but quickly turn into disillusion and mistrust whenever they are confronted with negative subjective experiences, such as those resulting from the breakdown of complex systems, wrong predictions, disclosures of attempted cover-ups of technological failures and denunciations of technological risks by the media.

Suggestions for easing the tensions

Several suggestions can be made in order to ease the tensions stemming from the five trends I have outlined and in order to put to profitable use the mutual reinforcement between science and democracy.

- First of all, education both in science and in democracy must be increased and bettered. On the one hand, ethical and social considerations should enter into natural scientists' training and more attention should be paid to preparing them for the various roles they have to play in universities, research centres, industries and political institutions. On the other, continuing education both in order to perceive and appreciate the advancements in scientific methods and theories and to be able to assess the social implications of science should play a much greater role in schools. Most citizens will probably not be able to understand specific scientific contents, but they can be educated to evaluate the main social consequences of given research projects. The mutual education of scientists and society should be a priority.
- Second, the role of the media should also change for the better. There is a lot of sloganizing and stereotyping in the media coverage of science news. The quality of science journalism should be improved. Media should restrain from 'banalizing' issues and help, on the contrary, to make scientific issues widely known and understood and to make the best scientists public figures, known and appreciated by the people.
- Third, scientists should learn to dialogue more among themselves, transcending disciplinary boundaries. Physicists, natural scientists and social scientists should increase the opportunities for debating common concerns, comparing their respective paradigms and methodologies, assessing the moral and social implications of science and technology.
- Fourth, scientists should speak more with the public. 'Science days' or 'science weeks' with the active involvement of prestigious scientists and teachers, decision-makers and citizens' associations should be organized with the aim of communicating science to the public. In today's knowledge society the public is more educated than in the past, but must be oriented within a scientific world of increasing complexity.
- Fifth, the institutions and procedures of participatory democracy should be used. Consensus conferences, where research strategies are discussed by all concerned stakeholders, polls and referenda like the recent Swiss one[1] in order to set policies in specific research areas which have relevant moral and social implications, citizens' panels and juries to take decisions on moral science-related issues, are all effective instances of both scientists' responsibility and citizens' involvement, which, if wisely employed, can combine the principles of scientific autonomy and of democratic debate.
- Finally, international scientific associations can play an important role. They can speak in the name of the weaker members of the scientific communities, organize truly international research projects, help to bridge the gap between scientists and their stakeholders, and contribute to finding a viable compromise between the inherently scientific quest for universality and the safeguard of culturally specific identities.

Note

1. In 1998, the Swiss electorate rejected a constitutional amendment proposing to ban the production, acquisition and distribution of transgenic animals, and the deliberate release of any genetically engineered organisms.

Action on climate change: a case study

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The complex structure of science with its many varied disciplines and the complex nature of democracy operating at different levels of decision-making both combine to produce an interactive relationship that is difficult to comprehend. The developments over the past two decades in relation to the global climate problem provide an example of the evolution of structures that enable scientists and decision-makers to combine their expertise and their efforts in order to tackle a global problem of concern to society. The progress from the multidisciplinary First World Climate Conference of 1979 and the Villach Conference of 1985, together with the Intergovernmental Panel on Climate Change of 1988 to the inclusive Second World Climate Conference of 1990 with its scientific and ministerial sessions, prepared the way for the launching of the Framework Convention on Climate Change in 1992 and the Kyoto Protocol of 1997 as a basis for action.

International cooperation in geophysics

The cooperation between scientists and decision-makers is such a broad and complex field that it is necessary to focus on a limited area within that vast field in a presentation such as this. The topic chosen is that of cooperation between scientific non-governmental organizations (NGOs) and specialized intergovernmental organizations (IGOs) in the area of geophysics and in particular in relation to climate change.

International cooperation in geophysics arose first in the 19th century when the rivalry of national expeditions to explore and study polar regions was replaced by coordinated expeditions leading to widespread synchronized observations. The Second International Meteorological Congress in 1879 approved the proposal for such a coordinated programme which was implemented as the First Polar Year 1882–83. Fifty years later, the International Meteorological Organization (forerunner of the present World Meteorological Organization) organized the Second Polar Year 1932-33 with the support of the International Union of Geodesy and Geophysics.

When a third such programme was proposed 25 years later to the International Council of Scientific Unions (now the International Council for Science, ICSU), the decision was made to broaden the scope from polar research to geophysical research aimed at global problems in all inaccessible regions. This resulted in the International Geophysical Year (IGY) of 1957-58, which had an enormous impact on geophysical research and international cooperation in science. Among the many significant events of the IGY was the successful launching in October 1957 of the first artificial satellite (Sputnik), which ushered in the Space Age.

The Global Atmospheric Research Programme

The discussions between 1961 and 1967 that led to the Global Atmospheric Research Programme (GARP) reflect a fundamental shift in the approach to global geophysical programmes, which, before that time, had been organized either solely by IGOs like WMO or solely by NGOs like ICSU. The change arose in relation to the cooperation for peaceful purposes in national space programmes. President John F. Kennedy, in his address to the General Assembly of the United Nations in September 1961, suggested ‘further cooperative efforts between all nations in weather predictions and eventually in weather control’.

In 1961 the General Assembly assigned both the operational and the research aspects to the WMO for study but a year later invited ICSU to develop an expanded programme of atmospheric research. There followed a period of rivalry and some confusion both between the two organizations and also within each of their internal structures. The discussions finally resulted in a formal agreement between WMO and ICSU as equal partners in October 1967. This agreement laid down that GARP was to be guided by a joint organizing committee, each member of which was nominated jointly by the two organizations. This first formal agreement between an IGO and an NGO as equal partners to promote global research proved over the next decade to have been well formulated to take maximum advantage of the complementary strengths of the two partners. The same structure was subsequently adopted for the World Climate Research Programme launched in 1980, for the Global Climate Observing System launched in 1992 and for the Global Ocean Observing System and Global Terrestrial Observing System launched in 1993.

The World Climate Research Programme

The building of new partnerships is also illustrated by the history of the developments in regard to climate studies and their effect on policy. towards the end of the 1970s, some scientists became concerned with the problems arising from the second objective of GARP to improve the understanding of the physical processes determining climate. An *ad hoc* group of scientists convened by WMO recommended the holding of a World Climate Conference and this recommendation was implemented in February 1979. As a result of this conference, it was decided to launch a World Climate Programme consisting of four separate components:

- the World Climate Research Programme (WMO and ICSU);
- the World Climate Data Programme (WMO);
- the World Climate Applications Programme (WMO);
- the World Climate Impacts Programme (United Nations Environment Programme, UNEP).

This First World Climate Conference was attended largely by scientists and the presentations and discussions consisted of the views of natural scientists on the nature of climate variation and change and the views of both natural and social scientists on the likely impact of climate change.

Interaction between scientists and decision-makers

In the early 1980s, scientists became increasing concerned about the problem of global warming. This led to the organization by WMO, UNEP and ICSU of the 1985 Villach Conference on the Assessment of the Role of Carbon Dioxide and Other Greenhouse Cases in Climate Variation and Climate Change. The Conference Statement drafted by the scientists at Villach included the first clear announcement of the growing consensus on global warming when it stated: ‘As a result of the increasing concentrations of greenhouse gases, it is now believed that in the first half of the next century a rise of global mean temperature could occur which is greater than any in man’s history.’ The Villach Conference represented a key step in promoting awareness of the problem, since the Conference Report provided an input to the Brundtland Report of 1987 on Environment and Development and found its way onto the agenda of the annual meeting of the G7. The linkage between scientists and decision-makers was further enhanced in 1988 when WMO and UNEP jointly established the Intergovernmental Panel on Climate Change to assess the current state of knowledge on climate change including the impacts of such change and the appropriate responses.

The Second World Climate Conference was held in November 1990 and was much broader in scope than the first Conference held a decade earlier. The Second World Climate Conference was organized in two parts: scientific and technical sessions resulting in a statement of experts followed by policy sessions resulting in a ministerial statement. In the scientific and technical sessions, there was greater emphasis on the likely socio-economic impacts of climate change than in 1979. For example, one of the four panel sessions was devoted to the topic of industrial responses to global warming. In the following years, government action increased in scope and pace. International landmarks were the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil, in June 1992, which led to negotiations on the Framework Convention on Climate Change and ultimately to the Kyoto Protocol on greenhouse gases of 1997.

This case study of initial independence and rivalry between NGOs and IGOs followed by cooperation leading to deeper understanding of the problem in its totality, and consequent agreement on policies advantageous to the global society, could serve as an example in other areas. One lesson to be learnt is that for a successful partnership one needs:

- to focus on a specific real problem;
- to establish parity of esteem among partners and acknowledge the unique contribution of each partner;
- to be totally committed to full and meaningful communication;
- to promote innovation and flexibility in finding appropriate structures and procedures.

The process is not easy but the results are well worth the effort involved.

Social science and democracy in Africa

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There are three salient contextual parameters within which the problem of (social) science and democracy in Africa must be situated. The problem itself can be posed broadly in terms of how (social) science can advance the prospects and possibilities for democracy in Africa. But whose (social) science and whose democracy? Under what conditions can (social) science advance the cause of democracy?

The diffusionist/cultural context of (social) science

The social sciences, as a body of interrelated disciplines whose primary focus is the study of humankind and the various intersecting institutions which humankind has established in the pursuit of collective, sometimes conflicting, even ambiguous, social goals, are now at a critical juncture in Africa. The paternity of African social science derives from the globalization of the knowledge industry, especially after the Second World War and the process of diffusion from one part of the world to the other that globalization has given rise to. But it is a paternity that is problematic, insofar as mainstream (social) science is an intrinsic cultural element in the struggle for hegemony on a world scale.

The problem of democracy in Africa has provided one arena within which African social science, in raising pertinent questions about ‘whose (social) science’ or ‘whose democracy’, is in confrontation with mainstream or dominant expatriate (i.e. Western) social science which, viewing African societies as ‘follower-societies,’ had reduced the problem of democracy in Africa simply to that of the replication of Western liberal democratic institutions.

However, the end of the Cold War and contemporary processes of globalization, among other developments, have combined in their effect to raise important questions about the imperative of autochthonous social and political organizations in Africa, based on the democratic premises of participation, transparency and accountability.

For example, the neo-liberal emphasis on market forces and on the inviolability of individual choices has renewed interest in democracy as the path to, and as the model for, collective self-development in Africa. With this has come a new challenge to African social science to map out for Africa alternative autochthonous democratic developmental paths to the liberal democratic one which, abstracted from the Western experience, has been put forward by mainstream Western social science as a universal model.

Much of the Western and other expatriate social science in Africa has tended to view the problem of democracy in Africa as basically one of replicating their respective (expatriate) democratic institutions in Africa. The challenge for African social science is how to face this expatriate social science view of democracy in Africa and, in doing so, to propose alternative concepts and tools for understanding, explaining and unscrambling the problem of democracy in Africa. An important aspect of this challenge has always been how to link teaching and research with social action, in such a way as to stipulate the conditions for democracy in Africa, based and founded on the lived experiences of African peoples and in opposition to anti-democratic forces and authoritarian regimes in Africa.

Arising out of this challenge is a new substantive and methodological focus at whose core are questions and issues about the character of the African state and Africa's political economy, the nature of the contemporary world system and of Africa's international relations, and how it constrains the terrain of choices open to African countries as they seek to democratize and develop.

The result of this new focus is the emergence of new and interesting perspectives on the problem of democracy and development in Africa. To name a few: the nature of class and class formation; the character of ethnic formations and conflicts; the impact of the external world and, especially, of the international financial institutions and world trade regimes on African political economies and social processes; issues of constitutionalism and the limiting structural and psychocultural constraints on democratization; the nature of social movements and the continuing struggle to expand the democratic space; the economic and political dimensions of internal and cross-national wars; civil-military relations and the conditions and prospects for demilitarization; and policy studies in the area of food security.

Recent experiments in democratic transitions in Africa have elicited interesting questions about the appropriateness of liberal democracy in and for Africa. While these democratic transitions have offered new challenges to the social sciences in Africa and to African social science, what has turned out to be problematic from the point of view of African social science is the mainstream expatriate social science conflation of the question of democracy in Africa with liberal democracy and its institutions. To illustrate: there is the need to resolve the design problem which ethnicity, in the form of the manipulative assertion of ethnic group rights in a situation of competitive electoral politics, poses for the simple majoritarian principle of 'winners-take-all' in liberal democracy, a principle whose adoption in many African countries has tended to turn competitive electoral politics into virtual warfare.

This is why a number of African social scientists who have been involved with or have studied the ongoing democratic transitions in some African countries, and pointing to the experience of Ethiopia, Nigeria and South Africa, have proposed other models of democracy, mainly social democratic ones, as alternatives to the liberal democratic one. The alternative models emphasize devolution of power and the dilution of the 'winners-take-all' principle in the form of the adoption of federal or quasi-federal and consociational principles to protect and assuage ethnic or minority interests, rights and fears.

The adversarial context of the policy process

A second context within which the relationship between (social) science and democracy is played out in Africa is in the critical advocacy role which African social science has been playing in support of democracy against authoritarian rule and anti-people social and economic policies on the continent. The searchlight is on the antecedental conditions for democracy. The intellectual role here is to speak the truth to power. In this sense, African social science has been and continues to be an integral part of the struggle for democracy on the continent. This has been at great cost in many African countries where social scientists have faced persecution, been forced into exile or have indulged in self-censorship. However, the power or ability of the regime to control intellectual work is limited, as the cost of persecution may be too much for the regime, which prefers to close down universities or to starve universities or research institutions of funds.

It is within this same adversarial context that African social science has been playing policy advisory roles in engineering democratic transitions, bringing multidisciplinary social science knowledge to bear on the design of democratic institutions and the formulation of complementary socio-economic policies.

This policy advisory role has not been without its dangers, giving rise to problems of legitimation and manipulation, and creating antinomies that the cohabitation of science and politics invariably generate, raising questions of credibility for African social science, leading to its frustration and powerlessness. All of this is not unrelated to the unpredictability of social processes, of social experimentation and the absence in the social sciences of a theory of democratic change.

Materialist context of the practice of science

The third context is the one provided by the economic crisis of the state and the general situation of underdevelopment which militate against the practice of social science in Africa. Most African universities and research institutions face acute funding problems. The conditions under which university teachers and students live and work are deplorable and harsh, making intellectual work and productivity an impossible task and ultimately undermining intellectual autonomy.

Science, discernment and democracy

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Science provides the forms of reasoning that make democracy work. Such reasoning allows individuals to assess data, weigh options and take decisions as to the best political choice. If this fundamental strategy of reasoning is absent, choices may be made purely on the basis of media images or personality traits rather than the quality, integrity and coherence of political programmes. This ‘banalization’ of the practice of democracy is, in my view, one of the major obstacles to achieving peaceful international governance and a global civil society. This is also one of the threats to democratization in its initial phases in many developing countries. To advance in these goals, then, it is necessary to strengthen public education with a view to fostering self-reflexivity for citizenship through a sound scientific training. Such an education enhances a rational perspective in public life.

In spite of its centrality to democracy and modernization, in recent times science has been criticized for what seem to be opposite reasons. Science is blamed both for the uncertainty implied in many of its recent theories and competing interpretations as well as for being too ‘monolithical’ in influencing society while running away with research that may change life as we know it even more.

Such claims can be countered by showing, on the one hand, that the uncertainty in scientific theories has always been there but had never been brought centre stage. Additionally, divergent interests of political and social actors are now militantly demanding that certain kinds of interpretations be derived from science. This happens more markedly in the social sciences. Yet, when interpretations are contradictory, it is social science that is blamed, not the pressures that use science to attempt to justify certain views or policies. One must be aware, then, that the more attempts are made by governments, institutions or societies to control science, the more all of them must be made accountable for its outcomes.

It is vital that the above be understood, since it relates directly to that great hope which now sustains our wonder of the new millennium, that is, democracy. However, for the reasons sketched above, in my judgement, unless the social sciences pick up again, we won’t be able to build democracies that will provide the rational grounds for a globalized world. This is for the following reasons.

In the 19th century, the new industrialism in Europe and the USA gave rise to concerns about equality and the ‘social’ and ‘cultural’ questions which had to be given attention in order to construct liberal democracies. This is the period during which sociology, political science and anthropology, among other social sciences, emerged as distinctive research and policy domains and were assigned the role of looking into these questions. Indeed, Wittrock goes as far as to argue that the social sciences ‘...were, from the beginning even, in the modern period, a fundamental aspect of this control exercise at vast scale on social reproduction which constitutes an intrinsic characteristic of the State’ (Wittrock, 1989).

Interestingly, the social sciences also became involved in research and advocacy in favour of subordinate groups within Western societies, thus contributing to stabilizing liberal democracies. In the international sphere, part of anthropology created the mirror of the ‘Other’ so that such questions could be explicated for Western society itself, while another part helped develop perspectives that gave impetus to national liberation struggles. What is very significant today is that this same exercise of self-reflexivity through the social sciences is considered by many politicians and institutions as a threat to democratization in developing countries.

Having been encouraged to become policy-relevant in the 1970s and 1980s, the social sciences are now being condemned for supposedly dominating policy formulation. Critics, among them even Jurgen Habermas, are referring to the 'scientification' of politics and strongly oppose the possibility of an 'expertocracy'. Which way should we have it, then? To go beyond such specific debates, we need to identify clearly who is asking what of the social sciences and expecting what kinds of results. Only then will the social sciences be useful in sustaining democracies while continuing to develop normative and intellectual horizons.

Issues on the role of social science in democratization are plentiful but I will take up only three of the main ones being discussed at present on the international agenda. One of them is that democracy cannot survive without a deep grounding in civic virtues. The first virtue must be the belief, on the part of citizens, that democracy is the best or, as is often stated, the least bad form of government. Such beliefs can only be developed through informed, plural public debates, led by agents whose knowledge will mostly come from social science research. Such research, however, often runs counter to the vested interests of political groups, corporations or individuals in economic, political or cultural life. This is why repressive or reactionary forces have always tried to control the social sciences.

The second civic virtue needed for democracy is tolerance. The United Nations, through UNESCO as a lead agency, has just ended a year-long project on tolerance. Racism, sexism and cultural exclusion must be combated through policy but individual prejudices must be confronted through permanent discussion and education, emphasizing that knowledge matters. Overcoming such exclusions requires systematic legal/judicial and political vigilance by individuals, communities and social movements that can be informed by the social sciences (Torres, 1998).

A great danger for democracy is the mis-representation of the 'Other' within societies or between nations. Today, we are seeing a surge of nationalist, ethnic and racist conflicts in many regions. Such discord arises out of power struggles fed by lack of knowledge or understanding of other ways of life, or is manipulated by unscrupulous political leaders. Against these prejudices, the World Commission on Culture and Development chaired by Javier Perez de Cuellar, in its report *Our Creative Diversity*, called for respect for all cultures that themselves have values of respect for other cultures.

But a complex question immediately comes to mind. Are all cultures compatible with democracy? This was the question we asked Adam Przeworski to answer, on the basis of his empirical research, in the first issue of the *World Culture Report*[1]. His answer was: 'While the intuition that culture matters for the viability of democratic institutions is born from our everyday experience, we should not be surprised that systematic evidence in favour of the cultural views is so weak. Historical comparisons of cultural traditions fail to identify which elements of culture are supposed to play the causal role and to specify what this causal role is' (Przeworski, 1998). This tells us that we still don't understand the dynamics of democracy and cultures and that this is ever-more necessary today to be able to manage multiculturalism and citizenship (see, among others, Bennet, 1998; Willett, 1998).

The third issue is that, in an Information Age which floods people with data they can no longer make sense of, discernment is the quality of thinking that social science must assist in developing for the new century. This requires an emphasis on the cognitive and analytical competencies that science helps develop, especially in young people. Such competencies should be fostered in public life, especially through the mass media. Encouraging the latter to orient itself towards 'edutainment', particularly in the new multimedia and the Internet, must be a priority both for governments and for the scientific community (Vinson, 1998).

I will end this telegraphically brief paper by accentuating that more reliable data and more analytical information provided by science means more interesting politics; uninteresting politics breed abstention, '*caudillismo*'[2] and fundamentalisms. For democracy to work, the social sciences especially must be able to provide the practical, embodied knowledge to empower people to make effective and realistic choices. Only with a constant flow of updated, trustworthy data and competing interpretations will people have the instruments to act with fairness, justice and recognition as practices of democracy.

Notes

1. Published biennially by UNESCO's Culture Sector.
2. '*Caudillismo*' is a Spanish term used to describe the phenomena in many countries, notably in Latin America, whereby strong men's words, attitudes and personality fill the central arena of politics to the exclusion of real political programmes and debates.

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Science and democracy: public attitudes to science and scientists

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The British public tends to judge the value of scientific advances by their end purpose. If no end purpose is made clear to them, many tend to assume implicitly that it has no useful purpose or even that its purpose will be detrimental rather than beneficial. The intensity of ethical objections to particular work, for example the use of animals in experimentation, is similarly significantly affected by understanding of what it is hoped will be achieved.

Scientific developments aimed directly at achieving improvements in human health care are the most valued by the public. However, the public is often ill informed about the purpose of scientific experimentation and public opinion is less supportive than it otherwise might be because not enough people instinctively make the connection between means and ends. Research for its own sake, and particularly research seen primarily as having a commercial motive, is unpopular.

Ignorance about the way in which science is regulated and restricted leads many members of the public to assume that the regulation is insufficient and this in turn makes them more likely to be hostile to science. Yet they are eager to receive such information and show intelligent interest when they do so. Regulatory bodies whose work was well publicized and which were seen to be free of control by government or other vested interests might significantly improve the climate of public opinion.

There is scepticism and mistrust in government and business alike and, although a majority of the public say they trust ‘scientists’, whenever a scientist’s employer or sponsor is mentioned, the veracity of the source becomes highly relevant: the scientists trusted by the highest proportion of people are those working for environmental non-governmental organizations (NGOs). It is clear that many members of the public assume (perhaps not consciously) that scientists cannot maintain their independence, integrity or objectivity when working for an interested party. Furthermore, in most fields of public controversy, the government is regarded as an interested party and neither it nor scientists seen to be working for it are trusted by a majority of the public.

Significant numbers of the public are prepared to use their power as consumers to put pressure on those involved when they object to a scientific procedure or principle. Science is important to people and they understand that it is. We are all affected by science, from today’s weather to global warming, from developing world famine to genetically modified organisms (GMOs), from new developments in medical research to space exploration, but we know what we don’t know and suspect those that do. That is human nature and scientists must understand that, in the world of the 21st century, it is no longer acceptable to have the good of mankind at heart, but to be seen to have the good of mankind at heart. If scientists do not do so, they run the risk of public scepticism at best, cynicism somewhere in the middle and distrust, suspicion and negative reaction at worst.

When given the chance, the public is perfectly prepared to judge science by weighing up benefits and drawbacks. The main issues which the public would take into account in determining whether a biological development is right or wrong are whether people would benefit from it and whether it would be safe to use. Other significant considerations would be whether the benefits outweighed the risks, whether or not it interfered with nature, whether animals would be harmed and – something the question was in fact testing – whether it was considered to be right or wrong.

The public has clear opinions that some scientific developments are beneficial and that others are not, as a survey of the Office of Science and Technology (OST) of the UK Department of Trade and Industry shows. Again, advances in human health score highest, clearly representing in the public’s mind the biggest benefit to arise from scientific developments. Specifically, the development of new medicines (antibiotics and vaccines) was most commonly mentioned by 57% in the quantitative stage, followed by transplants of various organs (51%), cures for or eradication of diseases (43%) and new operations/surgery (31%). These medical benefits are clearly widely felt to be beneficial to society and we found almost no advocates of a contrary view.

One conclusion that seems clear from the OST survey is that scientific developments can gain quick acceptance if the public has wide experience of them and finds them useful.

A particularly clear instance of an ethical issue to be resolved in judging science is the question of experimentation on animals. This was considered in considerably more detail in a survey for *New Scientist* magazine. Though this was an exploration of a specific scientific issue, it may be considered to have much wider implications as an exemplification of the way in which, and extent to which, the public is prepared to trade off its ethical objections to scientific processes or developments in the light of the concrete benefits to which they are intended to lead.

The purpose of an animal experiment has a significant effect on the public's likelihood, or not, of approving of it. The public differentiates substantially between curing leukaemia in children on the one hand and testing cosmetics on the other. Where no pain for the animal is involved, the balance of opinion is in favour of eight out of the nine experiments for mice and seven out of the nine for monkeys. The public's perception of the purpose of scientific development also seems to affect its acceptance of procedures where its objection is probably principally a perceived health risk rather than ethical objections. This is illustrated by the case of genetic engineering.

Since it seems clear that public attitudes to science are very largely determined by perceptions of what it is intended to achieve, public knowledge about and understanding of science is clearly important. Unfortunately, such knowledge and understanding seems limited; but the public itself is eager to rectify this if information can only be made available to it. The vast majority of the public are at least aware of major scientific developments that have been reported (whether or not they have yet been put to any practical use which is directly benefiting the public).

A survey on Public Understanding of Risk for the Better Regulation Office of the Cabinet Office explored in greater depth the relationship between perceived risk of scientific developments and self-assessed level of knowledge. Market and Opinion Research International Ltd (MORI) listed six possible health risks and asked the public how well informed they felt about each, which they thought posed a serious threat to them or their family, and on which the government should legislate or provide advice and information (Figure 1).

Figure 1.

Q On this card are a number of issues that have been described as health risks. Which, if any, do you feel well informed about?

Q Still thinking about the same issues, which, if any, do you think pose a serious risk to you and your family?

Q For which of these, if any, do you think there should be more Government legislation?

Q Alternatively, for which of these, if any, do you think the Government should restrict itself to providing advice and information?

	Informed %	Risk %	Legislate %	Advice %
Smoking	90	43	26	35
Unhealthy diet	61	32	15	38
Genetically modified food	16	31	53	24
Too much alcohol consumption	66	22	39	31
Measles, Mumps and Rubella (MMR) vaccines	36	14	20	27
Raw (unpasteurized) milk	15	10	12	20
Other	1	1	1	1
None of these	1	15	11	18
Don't know	1	2	3	7

Source: MORI/Better Regulation Unit (Cabinet Office) 9-19 January 1999
Base: 1 015 British adults aged 16+

This suggests that the general principle still stands: the better informed the public is by official and reliable sources, all other things being equal, the more acceptable they are likely to find scientific development.

There is strong support for the Government to be more open in its decision-making process. Over nine in ten think it should be more open (and 61% strongly agree), and eight in ten think that the Government should release what information it does have even when it is unsure of the full facts (43% strongly agree). This reflects one of the most powerful findings from our qualitative study.

Nevertheless, the majority of the public generally trust scientists to tell the truth. In general, scientists perform reasonably well (but not outstandingly) when compared with other groups on how far the public trusts them to tell the truth.

This can be tested in two ways. MORI's standard 'veracity' test (last conducted for the British Medical Association in January 1999) asks respondents to judge for each group whether they are generally trusted or not; in both 1997 and 1999, 63% of the public said they trusted scientists, putting them ahead of the benchmark figure (56% in 1997 and 60% in 1990) of 'the ordinary man/woman in the street', but well behind the most trusted groups, doctors and teachers, and indeed behind professors. (By way of contrast, when the Louis Harris polling organization asked an identical question in the USA in 1998, scientists came near the top of the list, trusted to tell the truth by 79% of the American public.)

Some scientists are trusted more than others. MORI surveys have persistently found that trust in scientists' pronouncements is affected by knowledge of who is sponsoring the scientists' research. MORI's Business and the Environment studies regularly test trust in different groups of scientists on the more specific question of what they have to say about environmental issues. The surveys invariably find that the public has considerably more confidence in what 'scientists working for environmental groups' have to say about environmental issues than 'scientists working in industry', who in turn have tended to be slightly more trusted than 'scientists working for the Government', although the latter marginally had the edge in the last (1998) survey (Figure 2).

Figure 2.

Q How much confidence would you have in what each of the following have to say about environmental issues?

	A GREAT DEAL/ A FAIR AMOUNT				NOT VERY MUCH/ NONE AT ALL			
	1995	96	97	98	95	96	97	98
	%	%	%	%	%	%	%	%
Scientists working for environmental groups	82	75	83	75	12	20	13	19
Scientists working in industry	48	45	47	43	45	49	48	50
Scientists working for government	38	32	44	46	55	63	50	47
Net lead (environmental groups over government)	44	43	39	29				

Source: MORI Annual Business & the Environment studies
Base: c. 2 000 British adults each year

The public rejects either the idea that scientists are capable of objective and reliable research or the idea that they can be trusted to tell the truth about it if it is not in their employers' interests to do so.

MORI's 1998 Corporate Social Responsibility survey found consumers willing to widen the scope of their selective consumerism from the product to the company. One in six (17%) said that in the past year or so they had boycotted a company's product on ethical grounds and 19% that they had chosen a product or service because of a company's ethical reputation; 28% had done one or the other. While a company's ethical reputation is, of course, by no means confined to science-related factors, this is certainly one of the factors such consumers take into account.

Appendix

General public surveys

The details of the surveys of the general public cited in this submission are as follows. In each case, the survey data were weighted to match the known profile of the national population.

- Multi-client cooperative survey on Corporate Social Responsibility: MORI interviewed a representative quota sample of 1 935 adults aged 15+ across Great Britain. Interviews were conducted face-to-face, in home, on 18 July-26 August 1998, on successive waves of MORI's regular Omnibus survey using CAPI (computer assisted personal interviewing) technology.
- Multi-client cooperative survey on Business and the Environment: MORI interviewed a representative quota sample of 1 823 adults aged 15+ across Great Britain. Interviews were conducted face-to-face, in home, on 4-11 September 1998, as part of MORI's regular Omnibus survey using CAPI technology. Clients included BP, Shell and WWF (UK).
- In the British fieldwork for the 1999 International Environment Monitor, MORI interviewed a representative quota sample of 975 adults aged 15+ across Great Britain. Interviews were conducted face-to-face, in home, on 7-10 May 1999, as part of MORI's regular Omnibus survey using CAPI technology. Clients included Greenpeace International.
- For the Better Regulation Unit of the Cabinet Office, MORI interviewed 1 015 members of the People's Panel aged 16+ across Great Britain, face-to-face, in home on 9-19 January 1999.
- For the Office of Science and Technology of the Department of Trade and Industry, a representative sample of 2 200 members of the People's Panel was selected, of which MORI interviewed 1 109 adults aged 16+ face-to-face, in home, across Great Britain and Northern Ireland on 13 March-14 April 1999. The quantitative survey was

accompanied by qualitative research, for which MORI conducted six two-day workshops around the United Kingdom between 5 December 1998 and 6 February 1999. In total 123 respondents attended the workshops. Three workshops were held in England, one in Scotland, one in Northern Ireland and one in Wales.

- For Motorola Ltd MORI interviewed a representative quota sample of 1 000 adults aged 15+ across Great Britain. Interviews were conducted face-to-face, in home, on 21-24 August 1998, as part of MORI's regular CAPI Omnibus survey. The data were published in *The British and Technology* 1998 Motorola Report.
- For the British Medical Association, MORI interviewed a representative quota sample of 2 051 adults aged 15+ across Great Britain. Interviews were conducted face-to-face, in home, on 8-12 January 1999, as part of MORI's regular CAPI Omnibus survey.
- For the Cancer Research Campaign, MORI interviewed a representative quota sample of 1 933 adults aged 15+ across Great Britain. Interviews were conducted face-to-face, in home, on 9-12 May 1997, as part of MORI's regular CAPI Omnibus survey.
- For the Technical Change Centre, MORI interviewed a representative quota sample of 1 824 adults aged 15+ across Great Britain. Interviews were conducted face-to-face, in home, on 4-9 June 1985 as part of MORI's regular Omnibus survey.
- For *New Scientist*, MORI interviewed a representative quota sample of 2 009 adults aged 15+ across Great Britain. Interviews were conducted face-to-face, in home, on 5-8 March 1999, as part of MORI's regular CAPI Omnibus survey. The survey was published in the edition of 22 May 1999.

Survey of environmental journalists

In MORI's 1998 survey of environmental journalists, 30 journalists from the national and regional press, specialist press and broadcasting organizations were approached, of whom 24 were interviewed (a response rate of 80%). Interviews were conducted face-to-face on 16 September-20 October 1998.

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Thematic meeting report

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Scientists have changed: the anarchy of individual scholars pursuing truth as they see it has been replaced by complex scientific bureaucracies, their members – ignorant of the social consequences of their projects – bent on routinizing relationships with their external environment, eliminating the human element from formula-based decision-making. Science has changed: evolving from the proverbial ivory tower into the main force of socio-economic development, it faces challenges from a public no longer equating change with progress, simultaneously running the danger of being exploited by policy-makers seeking endorsements from science to legitimize what they have resolved to enact. Democracy is changing into a discursive democracy, with citizen movements and non-governmental organizations demanding participation in agenda-setting and decision-making.

In view of a growing gap between expert knowledge and general knowledge, society certainly should be educated. Affinities between science and democracies – approaching truth here, deciding on viable policies there by accepting competing views, assessing data, weighing options – should be put to profitable use. But to an even greater extent, scientists should be educated, should be versed in the considerably different roles they may expect to play in academe, industry and polity. Ethical and societal considerations should enter natural scientists' training in order to counteract professional myopia – the tendency to close off, as functionally 'irrational', anything which is not predictable or, even better, controllable.

Scientists' problem with the public is not merely one of increased acceptance. Scientists must learn about people being motivated by values no less than by interests, so as not to be exploited by policy-makers or to blindly concur with bureaucrats in equating their mission with 'public interest'. Science and democracy interact by means of both knowledge and power. In that process, natural scientists must form partnerships, such as ‘consensus conferences’ – with social scientists, with the public.

These are the general ideas that drove the meeting. The present report is not designed as an agenda. However, it might – and should be – translated into two agendas for serious activity in the near future. One would be a conference agenda. The meeting was in complete consensus in favour of a full-scale conference on ‘the mutual education of scientists and society, to be sponsored by an appropriate international agency and organized by the relevant international learned societies’. The second would be a research agenda: individual social scientists would engage in methodical case studies on issues and decisions of salient importance to society, in which natural and social scientists were key players.

Introduction

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Usually, there are three different reasons for communicating scientific knowledge. First of all: scientific knowledge is of use to everyone. Of high usability, for example, is medical advice or meteorological information. The second reason: science is part of our culture and everybody has the right to share this knowledge. The third reason for communicating science is: scientific knowledge may alter the world. Our daily life is influenced to a high degree by scientific knowledge. Often this influence is of good value to most of us – like most technologies. But increasingly, scientific influence is regarded as risky or even dangerous, e.g. nuclear power or genetic engineering. Societies have to decide on those issues and therefore people have to be informed about that kind of science. They should know how to vote on the development of these technologies.

In all these areas of popularizing and communicating scientific knowledge, the media have to play an important role. Where scientific knowledge is of use to everyone, the media have to distribute that knowledge. That's the service function the media often have to play. Where science may provide a new insight into how the world is functioning, the media should disseminate these discoveries in special sections or magazines. That's the cultural aspect of science reporting. And where science itself is under scrutiny, the media have to provide arguments and room or time for discussion. That's the democratic argument for science communication.

This afternoon, we will focus on five key issues in science communication and popularization: firstly we will have a look at a big scientific research plant, the European Laboratory for Theoretical Physics (CERN). Paola Catapano will present the efforts of the communication group at CERN and will elucidate the difficulties scientists have to face when communicating such complicated matters as fundamental physics.

Secondly we will have a closer look at the scientists themselves. Toss Gascoigne from the Federation of Australian Scientific and Technological Societies has deep experience in training scientists to understand and love the media (with a contribution from Jenni Metcalfe).

Thirdly Carol Rogers will look at the audiences, the missing variable in science communication. So far we know very little about how audiences make sense of information about complex scientific issues. This presentation will offer several audience-centred approaches for modifying media coverage and we all are keen to get this information.

Fourthly we will have a look at a developing country, Colombia. Nohora Elizabeth Hoyos is Director of the largest science centre in South America, Maloka. She will answering the question: science communication – an exotic luxury?

Fifthly we will look at an organization deeply experienced in science communication: the British Association for the Advancement of Science. Peter Briggs will highlight the events the BAAS is organizing, such as the National Week of Science or the Science Festival. These events create opportunities for direct contact between scientists and the public but are also a valuable source for the media.

Science communication: a duty of scientists

Paola Catapano
Communication and Public Education Group, CERN, Geneva, Switzerland

The gap between science and society

'We have arranged a global civilization in which most crucial elements profoundly depend on science and technology. We have also arranged things so that almost no one understands science and technology. This is a prescription for disaster. We might get away with it for a while, but sooner or later this combustible mixture of ignorance and power is going to blow up in our faces.' (Carl Sagan, *A Demon Haunted World*, 1996)

No better quote than that above by late American astrophysicist Carl Sagan could describe the existing undeniable gap between science and society. A closer look at this gap reveals that it can be described as a communication problem between science and society on the one hand and science and the media on the other, a problem that is further complicated by the way scientists communicate science. There are indeed natural barriers between what can be defined as different worlds obeying different rules, guided by different priorities, referring to often-conflicting parameters and speaking different languages. Examples of each of the above cases are given in the following paragraphs.

The barriers between science and the public

Here again, the best description comes from another scientist who devoted a lot of his energy to the cause of making science more accessible to society, Richard Feynman: 'People want to know things that we don't know.... [they prefer] the secure knowledge of an understood but tedious past to a frontier of ignorance constantly in flux, an unknown but enchanting future.'

Richard Feynman, winner of the Nobel Prize for Physics and an inspiring figure in his time, most effectively highlights the fact that the perception the public has of science is generally ill-conceived. People expect firm and secure answers to global problems from science, an activity that is aimed at pushing the frontiers of knowledge as far as possible and that is by definition 'unknown' and surrounded by uncertainty. People need quick fixes to urgent problems, whereas scientific research is a long-term process in which real milestones and sudden discoveries are extremely rare and unexpected. Science is a history of failed attempts based on hypotheses that are continuously reviewed and adjusted. The results of scientific research, in particular in the case of elementary particle physics, are so much at the frontier of knowledge that they cannot be 'consumed' by the public, except over very long time-scales.

The barriers between science and the media

Undeniably, the media context is very different from the scientific context and the production of a scientific truth clashes with the production of news. The timing of news production is extremely short, whereas scientific results need patience and long discussions before publication; media tend to isolate a *vedette* [a star performer], whereas research is increasingly a collective process. The language of the media is simplified and needs examples and strong images that are rarely to be found in science. The translation of scientific jargon without betraying the scientific truth is very difficult.

An example of such difficulties is the way the world media covered the announcement of the production of the first nine anti-hydrogen atoms at the European Laboratory for Theoretical Physics (CERN) in 1996. A very low-profile press release about a minor experiment carried out at CERN with very few resources provoked an avalanche of sensational headlines in the world press for months:

- Antimatter bomb devastating, but very unlikely to be produced (*Financial Times*, 20-21 January 1996);
- C'est mille fois plus puissant qu'une réaction nucléaire normale (*L'Evènement du Jeudi*, 7 January 1996);
- Premiers Pas dans l'Antimonde (*Libération*, 7 January 1996);
- Première Mondiale: Et l'Antimatière fut! (*Sciences Avenir*, February 1996);
- Eine Revolution in der Physik (*Die Woche*, 12 January 1996);
- Oltre la materia, al di là della luce (*Il Corriere della Sera*, 14 January 1996).

...to quote but a few!

Most articles were centred on the sensational but scientifically groundless aspects that the subject of anti-matter evokes – bombs, intergalactic engines, nuclear power and even the Anti-Christ! – whereas the scientific and technical interest of the news was completely neglected. And many more articles by far were produced on this minor CERN experiment than on the approval of the Large Hadron Collider (LHC), a project that has been vital for the future of the organization.

Scientists and science communication

To illustrate the difficulties of science communication made by scientists, some results from two surveys (Catapano, 1998) conducted in 1997 on visitors to two similar particle physics exhibitions, Quark und Higgs in Vienna and Quark 2000 in Rome, are presented. Quark 2000 was organized by the Italian National Body for Nuclear Physics (INFN) in the spring of 1997; Quark und Higgs took place in the autumn of the same year at the Austrian Academy of Sciences, organized by the Academy's physicists. Both the themes of the exhibitions and the results of the surveys on their visitors were very similar. They are briefly summarized as follows:

- The majority of the public could not understand the texts of the exhibitions without the help of guides.
- Despite the good intentions (a declared objective of the Rome exhibition was 'to overcome the language barriers, to provide information accessible to all'), the effort to translate technical jargon was not sufficient in both exhibitions. As an example of the average level of difficulty, here is a caption from the Rome exhibition, 'The symmetry between quark and lepton families re-established by quark c was broken with the discovery at SPEAR of a new heavy lepton, the TAU, belonging to a third leptonic family.'
- The surveys' results highlight public misinterpretation of basic science and a failure to understand its priorities.

When asked about how to prioritize the distribution of funds among various branches of science, after visiting exhibitions meant to promote particle physics, visitors to both almost unanimously converged on medicine as a top priority for scientific research (65% in Rome and 72% in Vienna), whereas physics research got 18% in Rome and only 2% in Vienna. Moreover, as many as 40% of the Austrian public even judged scientific research dangerous! These data confirm that the general public is confused about the priorities of scientific research and cannot distinguish properly between pure and applied research. The visitors expressed their judgement on particle physics – that is the example of pure research – on the basis of its applications and relevance to daily life. Understanding the importance of pure research for the advancement of knowledge and the progress of civilization is essential for the future of a worldwide laboratory like CERN.

CERN's role and responsibility in bridging the gap

An institution like CERN has a key role to play in trying to bridge the science-society gap. In the case of CERN, the promotion of the institutional image coincides with the popularization of fundamental physics and the role of science as a engine of progress for knowledge. It is therefore a social duty for CERN scientists to communicate science, a 'cultural' and 'social' responsibility they cannot ignore.

CERN in brief

CERN, an old acronym still in use for today's European Laboratory for Particle Physics, is the world's largest laboratory devoted to research in elementary particle physics. Based at the Swiss-French border on the outskirts of the city of Geneva and founded in 1954, today it has 20 member states (Bulgaria joined in June 1999), is used by over 7 000 scientists from 500 research institutes in 80 countries and its facilities are run and maintained by a staff of 2 700. CERN's mission is pure science: studying the innermost structure of the tiniest building blocks of nature, particles, and the way they interact, forces. In the 45 years of its existence, scientists at CERN have made giant steps in the understanding of nature's basic laws, some of them having been awarded the Nobel Prize for Physics. But more than anything else, CERN is a shining example of international collaboration. Many spin-offs have been derived from the technology developed by CERN's scientists for their experiments, last but not least the World Wide Web, invented at CERN in 1990.

The public communication of science at CERN

It is only recently that the scientific community at CERN has developed an awareness that the future of fundamental physics also and increasingly depends on society's commitment and the interests of its non-physicist citizens. Indeed, until 15 years ago the intrinsic value of the institution was perceived as self-evident. In the last decade, each new progress in physics has opened new questions, the answers to which have required higher and higher energies and more and more complex – and expensive – machines and experiments. The end of the Cold War and other socio-political factors have made funds more difficult to obtain for particle physics, or at least less automatically guaranteed. Thus, a greater emphasis on public communication activities has ensued as a strategy against isolation.

Communication activities that have developed in the past 15 years at CERN to meet a spontaneous demand have been strengthened by the latest management and new activities are being launched by the present management. Here follows a brief list of present activities in science communication.

Press Office: welcomes circa 400 journalists and television and radio crews, issues 10 or so press releases per year.

Publications for the general public: a range of short and simply written brochures describing CERN's main scientific activities and achievements was published in 1995-96 and is being renewed every year.

New Web pages especially designed for the public were put up on the CERN website in 1998.

Exhibitions: the on-site exhibition Microcosm was revamped and made more accessible to its target public of 15-year-old school pupils in September 1997 and a new travelling exhibition, $E=mc^2$, started touring the organization's member states in 1997.

An Outreach Network including representatives from each member state was started in 1998 to find a synergy and exchange information on each member state's outreach projects.

Public Visits and Events were revamped in 1995 and have now become a permanent successful feature of the communication policy with an average of 30 000 visitors a year; open days attracting 20 000 visitors in a single day; and a whole range of special events organized every 18 months since 1996.

New educational activities for local (Swiss and French) schools as well as schools from the member states started in school year 1998-99.

LIVE FROM CERN, a Webcasting project of live connections with science in action at CERN in collaboration with The Exploratorium in San Francisco, has just been launched and a pilot is planned for November 1999.

Such a widespread awareness of the importance of communicating with the general public among CERN scientists is confirmed by a recent survey conducted among the 235 volunteer guides the Visits Service recruits among the resident scientists of the Laboratory for its Public Visits programme. Some 51% of the guides are recruited among CERN doctoral or post-doctoral students. Among the guides, 60% declared that the main reason for devoting part of their time to taking visitors around the Laboratory was that they felt it their duty as scientists to communicate with the general public.

Conclusions

The scientific community's awareness of the importance of communicating with the general public and of its role in bridging the gap is a very important change that has occurred in the last five years. However, reaching a widespread awareness among scientists is only half of the work. A quantum jump in the quality of the communication made by scientists is needed. Communicating science to a non-knowledgeable public means translating ideas and concepts that are often extremely complex and distant from common sense into a comprehensible language and creating interest in the public without betraying the scientific truth. A very difficult task indeed! As is indicated by the case studies above (Quark und Higgs and Quark 2000), when scientists turn to the public they do not make enough effort to translate their jargon nor to analyse public perceptions and needs. As obvious as it may appear, the target public, an essential starting point, has too often been neglected in the popularization of fundamental physics. Scientists need therefore to understand that, in the job of public communication, they need to be assisted by a wide range of different competencies if they want to reach the target public. Any science communication action, like any marketing initiative, should be based on a public-oriented strategy. The scientific community needs to import from marketing a 'customer satisfaction' model to be able to identify the gap between expectations and perceptions, previous knowledge and the new information they want to communicate to their public.

As a non-physicist working for the physics community, I know that pointing to the example of marketing might not be an effective strategy with scientists. More convincing models for my colleagues are to be found among the physics 'gurus'. At the beginning of this presentation I quoted Carl Sagan and Richard Feynman, two physicists of the past generation who made of science communication a life's mission. There are today living examples among contemporary physicists such as Nobel laureates Georges Charpak and Leon Lederman, who are devoting a lot of effort to improving the quality of science education in primary schools. I will conclude with a quote from Carlo Rubbia, another Nobel laureate in Physics, who indicated Galileo Galilei as the father of science popularization: 'Galileo was the first to open science to a larger community... Part of his published work was in Italian rather than in Latin in order to reach as wide a circle as possible outside the limited scientific community... He was the skilful initiator of a teaching and popularization process for which we feel a great need today.' (C. Rubbia, tribute to Galileo in Padua, 1992)

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Training scientists to understand and love the media

Toss Gascoigne and Jenni Metcalfe
Federation of Australian Scientific and Technological Societies, Deakin West, Australia

We have been running two-day media skills workshops for scientists in Australia over the past seven years. The workshops have also been run in South Africa and New Zealand. An essential element of the workshops is the involvement of five working journalists. Many people in this area recognize the cultural barriers between the scientific and media worlds. Scientists have a stereotypic image of journalists and journalists have similar images of scientists, views often shared by the public. For example, scientists participating in focus group discussions felt that the public saw them as 'boring men in white coats in a world of their own, people whose actions and motives are to be regarded with suspicion or distaste' (Gascoigne and Metcalfe, 1997). Journalists are also aware of their negative image in the community and the poor ratings their occupation gets in opinion polls.

This paper outlines the workshops, summarizes the response of the participants to them and describes a change in attitude by participants to journalists over the course of the workshop.

The workshops

The workshops generally run for two days and involve a maximum of 10 scientist participants. They use two presenters to ensure that the sessions are lively and entertaining, and to ensure that each participant gets individual assistance and feedback. They have been especially designed for scientists and technical people and are not run for any other groups in the community.

At the beginning of each workshop, participants are asked to select (from a list of eight options) the three top things they wish to gain from the course. The most popular response in every workshop is 'tailoring a scientific message to suit the media, without compromising the quality of the message' (Gascoigne and Metcalfe, 1998). The least popular response is generally 'understanding the pressures and constraints under which journalists work'.

Five working journalists (usually two each from television and radio and one from print) are brought in to lead sessions on their area of expertise and to give all participants experience in being interviewed. Each of the journalists gives an informal presentation about how their particular medium operates and what they need to make a science story work for them.

Demonstration interviews by journalists are given in front of the whole group then each participant withdraws to do individual interviews with journalists. Feedback on performance and story value is given by both the journalists and the workshop presenters. Despite their initial lack of interest in the working life of journalists, the scientists have plenty of questions to ask them about their routines.

Some time is spent on examining the reasons why scientists should communicate. These may include:

- maintaining or increasing funding;
- improving the image of the organization;
- ensuring that the public has access to correct information;
- for public accountability (usually public funds support the research);
- to improve the adoption of technology;
- to gain personal recognition.

One of the ways cultural barriers between industry and researchers can be broken down is through public dialogue. The media play a vital role in enabling this dialogue by publishing simple and accessible explanations from the point of view of all the groups involved. Scientists with a desire to commercialize their work have often found the media a useful tool to help them reach partners in the process.

What do scientists think of the media and journalists?

Scientists are generally suspicious of the media, especially if they have had little experience. Such inexperienced media performers 'essentially distrust the media and doubt the media's potential to help their science. They are particularly fearful of misrepresentation, inaccuracy and loss of control and see the media as exploitative and manipulative' (Gascoigne and Metcalfe, 1997).

Training in media skills can help overcome the barriers between scientists and journalists. An initial assessment of the workshops found that 'most of the media workshop graduates feel that they have better control over their media appearances, that it is helpful to their communication efforts, and that they now feel more comfortable working with the media' (Gascoigne and Metcalfe, 1997).

At the end of each workshop, participants complete an evaluation sheet. Of the 84 participants in 10 workshops in Australia and New Zealand surveyed for this paper, many (81%) mentioned their interaction with journalists as a highlight of the workshop:

- 'I liked the contact with working journalists.'
- 'It broke down our prejudices about journalists.'
- 'The opportunity to experience interviews with different media was great.'
- 'Being able to talk to working journalists and see them as people not to be feared.'
- 'Practical hands-on experience at delivering interviews with real industry people.'
- 'It was interesting to get insights about journalists, their job, their pressures, what sells a story and how best to do it.'

This was also true for scientists who participated in workshops in South Africa.

Changing their minds about journalists

Media skills workshop participants in Australia were asked to state their views of journalists. A sheet with 12 words was distributed at the beginning of the workshop, and participants rated journalists on a one ('strongly agree') to seven ('strongly disagree') score for each word.

At the end of the workshop, after they had had intensive dealings with five different journalists, they were given an identical (but unmarked) sheet and asked to score the words again. The sheet contained both positive and negative words: helpful, reliable, sensationalize, trivialize, thorough, accurate, distort, superficial, interested, concerned, unprincipled, trustworthy. The views of the same 84 scientists as above were collated and the 'before' answers compared to the 'after' answers. The results show participants changed their views of journalists over the course of the two-day workshop quite markedly and were much more positive about journalists after meeting them.

After the workshops, participants were more likely to think of journalists as helpful, thorough, concerned, reliable, accurate, trustworthy, interested and hard working. The average change measured over all 84 responses to the 12 questions was a swing of about one in a positive direction. In other words, if a participant had scored journalists as '3' on the word 'sensationalize' at the beginning of the course, at the end they would, on the average, re-score them as '4'.

In many cases, the differences were quite dramatic. Seventy-four of the participants changed their score on the word 'sensationalize', all of them in a positive direction. Fifty-seven changed their score on 'unprincipled' and, again, all in a positive direction. 'Distort' got 56 changes, 54 of them positive (but two responses were negative). 'Trivialize' (40 positive, 6 negative) and 'superficial' (31 positive, 4 negative) also drew strong results.

The journalists' views

The media skills workshops could also be called 'scientific skills for journalists'. For many journalists, this is their first contact with scientists and some are initially either nervous or expecting to be bored by dull stories about jargon-ridden scientific work. Instead, the journalists find the atmosphere relaxing and the scientists much less threatening than they expected. They find many of the stories exciting and want to write or broadcast them. It is rare that at least some media coverage does not emerge from each workshop.

In responding to a questionnaire, journalists who had participated in recent workshops were generally enthusiastic about the value of media skills training:

- 'I think the workshops are extremely useful in training scientists to deal with the media, mainly because they teach scientists to speak like "normal" people.'
- 'Really, we're quite nice people, and all we want is to have a clear and concise chat about new scientific breakthroughs. Easy!'
- 'They break down the fear barrier and encourage scientists to think of the importance of their work in a way the general public can understand.'
- 'I think these workshops are a very valuable part of improving the way in which scientists can tell their stories and make science more relevant.'
- 'I was refreshingly surprised by their desire to become media-savvy. All had good stories to tell and most were able to express themselves in easy-to-understand terminology.'

Conclusion

Interaction with journalists over a two-days media skills workshop is quite powerful in changing scientists' attitudes. They leave the workshops seeing journalists more as potential allies than as threats to be avoided. Journalists also change. It is highly likely that they are now more aware of the scientific culture, evidenced by their willingness to participate in further workshops.

Media skills training is an important tool for helping scientists to feel more comfortable about working with the media. By getting scientists and journalists involved in a dialogue, it makes both sides aware of the constraints and pressures that the other operates under. The breakdown of such barriers should improve both the quantity and quality of coverage of science in the future.

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Audiences: the missing variable in science communication

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One of the key actors – and one often overlooked – in the science communication process is what I call the missing variable: the audience. The scientific community has been increasingly concerned about communicating with this audience – that is, with a larger, non-technical public – throughout the 20th century. At the same time, journalists have an interest in reaching those very same people, who comprise the mass media audience.

Yet both of these groups – scientists and journalists – seem to have little understanding of the needs, interests and concerns of those very people they are trying to reach. In fact, although scientists regularly decry the lack of scientific understanding on the part of the public, we are regularly reminded that scientists themselves actually know very little about the public. Similarly, scholars consistently find that journalists know little about their audiences overall. Ask journalists about feedback from readers, listeners, and viewers; the journalists will say they rarely, if ever, get any.

We do know some things about this audience for science information, however. First of all, we know that people are very interested in science. Evidence of this interest is easy to come by in such things as the popularity of television programmes such as the US television programme NOVA, visits to science museums all over the world and books about science directed towards general audiences. In addition, surveys regularly reflect this interest, including a recent study, conducted for the US National Science Board, which found that nearly 50% of Americans were very interested in scientific discoveries and new technologies, some 70% in medical discoveries and 52% in environmental issues (National Science Board, 1998, pp. 7-5).

People also tell us that they are interested in having science widely covered in the mass media. In the USA, studies as long ago as the late 1950s and as recently as the early 1990s found that a ‘relatively large number of people’ wanted to see mass media coverage of science (Survey Research Center, 1958, p. 3). In addition, a ‘majority of the public nationwide considers science news to be of equal importance to every other major area of news coverage....’ (Scientists’ Institute for Public Information, 1993, p. 2).

Although people might be interested in science, we are told from numerous studies that people don’t know much about science. Certainly, they seem to have a poor understanding of the body of knowledge that is science (see, for example, the National Science Board’s Science and Engineering Indicators, 1998).

But I would argue that such a picture of a scientifically illiterate public stands in stark contrast to the more complex one painted by several scholars, who have argued that one-dimensional quantitative measures fail to take into account the context-specific way that most people understand science (see, for example, Wynne, 1993).

Surveys documenting public interest in science, along with work that explores the complex ways people understand science, serve to remind us that we often sell the public short. This is where the missing variable in the title of my talk comes in. I’d suggest that one way that scientists and journalists can learn more about the public and about how to better provide understandable information to lay audiences is actually to listen to them. Some of my own work on how people make sense of media coverage of AIDS and global warming offers some possibilities.

The study included a series of six focus groups consisting of adults who had no particular expertise in AIDS or global warming. The AIDS stories used in the focus groups primarily reported on the success of using combination drug therapies, including the new protease inhibitors, in patients with AIDS. The global warming stories reported on the consensus statement approved by the Intergovernmental Panel on Climate Change (IPCC) in 1995 that said there is ‘a discernible human influence on global climate’.

Regardless of whether the story was about AIDS or global warming and regardless of whether the story appeared in newspapers or on television or radio, two story characteristics stood out as causing particular problems for focus group participants as they sought to understand the story. These were lack of information and lack of context.

One of the biggest concerns study participants expressed was that the stories lacked basic information they needed for understanding. Specifically, they found the stories assumed levels of knowledge that they didn’t have. In the AIDS stories, for example, audiences wanted more explanation to enable them to make sense of the information. They needed to know the basics about drugs being discussed and the relationship between AIDS and HIV. Equally important, two issues found to be especially significant to the focus group participants and which they discussed at great length – side-effects and costs – were barely mentioned in any of the reports.

As for the global warming reports, the focus group participants also wanted more basic information – in this case about how the experts came to 'know' about the human influence, where the facts came from. They wanted to be 'let in' to the decision-making process. But further, they wanted to know more about the experts themselves in order to evaluate their credibility. They were unwilling to take the people featured in the stories at face value.

Repeatedly, focus group participants expressed frustration with the lack of context provided in stories. With both AIDS and global warming, they wanted to know where this new information fitted into the bigger picture of what came before and what was next. They wanted to know how the new information related to other things – for AIDS, the other drugs; for global warming, previous weather events. Some of the missing context had to do with the uncertainties inherent in the issues themselves. With AIDS, for example, that context included information about what the long-term effects of the medications were. With global warming, it included the implications for the planet and the people on it that the Earth was heating up.

With this in mind, what particular strategies might be useful in bridging that gap between the interests and needs of audiences and the content of the stories journalists produce, taking into account such constraints as time, space and resources?

First of all, in a very basic sense, scientists and journalists need to make a greater effort to understand the audiences they are trying to reach. They can't simply assume that the audiences share their background, knowledge or attention to the issues. A great deal of research has been conducted over the years on the dynamic ways in which people process information to make sense of their world and to manage the uncertainties that are regular parts of their lives. Both scientists and journalists would do well to incorporate more of this knowledge into their work.

Further, the Internet and World Wide Web could provide new and meaningful ways for journalists and scientists to become better acquainted with audience needs and interests. Opportunities for audiences to send e-mail messages to journalists and news media outlets and to scientists and scientific organizations, asking questions and providing comments, are now a reality. A word of caution, however. Although people's access to the Internet and World Wide Web is increasing exponentially, such access is still largely the province of a limited segment of society, not only throughout the world but even in a highly developed country like the USA.

Of course, reporters need to provide the basic 'who, what, when, where, why and how' in writing about science, as well as about other complex topics. However, writers need to go beyond the basics and provide complete information and avoid making assumptions about the background and knowledge level of their audience. And sources need to be sure the journalists have that complete information.

In addition to information, these audiences wanted context. Journalists need to emphasize why the story is important, to ask the 'so what' question and scientists need to be willing to provide that information. Audiences need to be given a sense of why they should care about the story and should be given enough background so that they can understand it (see, for example, Crane, 1992; Levy *et al.*, 1986). Almost to a person, these focus group participants asked for that kind of information.

Is the missing variable – the audience – an essential factor to consider in the science communication process? My answer would be a resounding 'yes'. Communication is about speaking AND listening so we have a truer understanding of the public's needs, interests and concerns. That's the only way to guarantee the long-term health and vitality of the news media as we know it, the long-term health and vitality of the scientific enterprise – and the conduct of science for the public good.

Note

An expanded version of the study discussed in this talk appears in Chapter 11, The importance of understanding audiences, in: S.M. Friedman, S. Dunwoody, and C.L. Rogers (eds.) (1999) *Communicating Uncertainty: Media Coverage of New and Controversial Science*, Lawrence Erlbaum Associates, Inc..

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Popularizing science: a necessity or a luxury in a developing country?

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Situation of the country

Colombia, with 40 million inhabitants, is the third-most populated country in Latin America after Brazil and Mexico, while covering the fourth-largest area in the region. Its population is predominately white, Spanish-speaking and Catholic. Santafé de Bogotá, the capital, has 8 million inhabitants and is located in the country's centre.

However, there are still strong social differences, as only 5.5% of the population belongs to the upper class and 60% to the poorest one. Like the rest of the region, the country is at a stage of intermediate economic development, with an annual per capita income of around US$ 2 500 and a relatively sustained rate of growth in gross national product (GNP) which has varied between 0% and 5% in the last 20 years. The population growth rate has substantially decreased in the last decade to reach 1.8% at present.

Despite this relatively favourable general situation, it is evident that the violence affecting the country in recent decades has been a major obstacle to sustaining social and economic progress, even if it is only due to the action of a minority of less than 1% of the population. The roots of this problem are multiple and have to be analysed with extreme care, since both historical and social factors must be taken into account. The present government is making great efforts to start negotiations with the different sectors of the community that are involved and for the first time in decades serious possibilities of reaching a long-lasting peace within a few years are seen on the horizon. However, the process to peace will be long and complex and will need fundamental changes in society that will imply sacrificing old privileges.

Education and science

Like the rest of Latin America, Colombia has to make an enormous effort in both education and science and technology in the next few years in order to reach the accelerated growth rates that will guarantee acceptable living standards to its population. Regional expenditure in research and development (R&D) is still very low and has not increased in the last decade. In contrast with eastern countries like the Republic of Korea or Singapore, where R&D has grown from 0.5% of GNP to more than 2% in 10 years, Latin America has maintained, with a few exceptions, a steady average of 0.4% over the same period.

Due largely to a strategy of cooperation between the scientific community, represented by the Colombian Association for the Advancement of Science (ACAC), and Colciencias, the National Science Institute, investment in Colombia has been more positive. Science and technology (S&T) expenditure increased from 0.15% of GNP in the last decade to almost 0.7% in 1996. These efforts gave rise in the 1990s to the drawing up of a legal framework for S&T and to the inclusion of the subject in the new Colombian constitution, which means a clear commitment by the country to this field. These legal instruments are the framework for scientific activity in the country and formed the basis for restructuring Colciencias, ascribing it to the Planning Ministry, and for the establishment of the National Science System.

The Colombian Association for the Advancement of Science

The Colombian Association for the Advancement of Science (ACAC), a private non-profit institution, has played a major role in the development of this field in the country through its leadership in science policy, specially regarding the promotion of legislation for S&T. In recent years, the ACAC has realized that public understanding of science is as important as the development of science itself and has started a dialogue between policy-makers, scientists and the general public. The ACAC has carried out programmes such as the biennial science fair Expo-Science Expo-Technology, the popularization journal *Innovation and Science*, the television programme 'Universes' and scientific activities for youth, which have reached millions of Colombians in the last 10 years. ACAC has also supported the Colombian Association of Scientific Journalism.

These activities have demonstrated the great interest of the general public in S&T and the importance of science education in constructing a modern and peaceful country. However, these programmes still have a limited influence and, therefore, ACAC has taken measures to implement new models of non-formal education, promoting creative thought.

Maloka, a success story

In the early 1990s, ACAC initiated studies for building an interactive science centre in Bogotá. We believe that institutions such as the third-generation science museums are valuable tools for complementing traditional education and contributing to public understanding of science. This idea became a reality when developers of a new quarter in Bogotá, Ciudad Salitre, offered land for that purpose.

Despite the lack of experience in this field, which was overcome by the promotion carried out by ACAC in recent years, the project received enthusiastic support from city authorities and the national government which, together, contributed around 60% of the financing. The private sector covered the remainder of costs, despite the difficult economic situation of the country, through different strategies.

Maloka, the name given to the centre, is a word used by many of the local Indian cultures to designate the most important place of the community where all meaningful activities converge. The construction of the centre began in April 1997 and it was formally inaugurated in December 1999 as an independent institution. Maloka is the largest science centre in South America, with an area of 22 000m^2, an underground construction of over 10 000m^2 and 7 000m^2 of free public area. Moreover, it is becoming a symbol of the nation's capability. Maloka is inspiring seven similar projects in Colombia and others in neighbouring countries.

The mission of Maloka is to contribute to the creation of a culture based on knowledge, incorporating technology into everyday lives and in production processes, within a framework of sustainable development. More than just a science centre, it is a national programme of non-formal education that strives to become a symbol for creativity, knowledge, education, self-confidence and commitment to our country to improve the quality of our lives.

Maloka has more than 200 interactive exhibits, integrating basic and social sciences, which have been designed and built in Colombia; it also has the first large-format theatre in South America, with the latest advanced projection and sound technology, which displays educational and recreational films.

In addition, Maloka presents a permanent educational and cultural programme that includes workshops, courses, etc., addressed in particular to teachers, students and families. It also has a very popular Web homepage, which has had more than 77 000 visitors in five months. In order to increase the impact of Maloka, we have developed travelling exhibitions complemented by educational activities. In February 1999, Maloka created three Science Clubs, which attract more than 200 children and youngsters who spend their free time in a variety of scientific activities. Some of them also guide our visitors in the Hall of Life.

Our project does not stop here: four months after opening, we were ready to start our second phase: more than 23 000m^2 of new exhibitions, experiments, laboratories, a vivarium for small animals and the big Hall of the Brain. All this is complemented by a convention centre for up to 700 people. More than 40 000 visitors in six months are a clear demonstration of the great role that the centre is playing in the country and of its potential to disseminate science knowledge and to improve science education.

In Colombia, more than in any other nation, we need urgently to recover confidence in our capabilities and to offer youth alternatives for thier development, to stimulate creativity and critical thought. We are working to extend the coverage of our programmes to minorities, old and disabled people and, of course, to the poorest layers of the population. As a fundamental tool for this purpose, we are designing special indicators to measure the social impact of our programmes.

To conclude, we in a developing country, more than in the rest of the world, must design all kinds of strategies to strengthen the scientific community and vigorously carry out integrated programmes to encourage public understanding of science. Science is not a luxury but an urgent necessity.

Science festivals and weeks: adaptable vehicles for science communication

Peter Briggs
British Association for the Advancement of Science, London, UK

Just as there has been an international growth in science centres in recent years, so too science festivals and weeks have developed across the globe. They take place in towns, cities and villages and as nationwide events. Like science centres they are a worldwide phenomenon with common characteristics but with each adapted to its particular circumstances. What works in Shanghai may not be appropriate in Edinburgh; and activities designed for Australia will not necessarily be successful in Austria.

I will talk about three events in the UK: the British Association for the Advancement of Science's (BAAS's) annual meeting, now renamed a festival of science; the Edinburgh International Science Festival; and the National Week of Science, Engineering and Technology (SET Week). They are not the only such events in the UK, which now boasts science festivals in towns and villages from the north of Scotland to the south of England.

The BAAS event started when the BAAS was founded in 1831. A meeting for scientists, it was initially an occasion for the announcement of discoveries and inventions and has a distinguished history. But the growth of scientific societies and the development of scientific journals made its original purpose largely redundant and, over the years, it has had to find a new role. So it slowly became what it is today, an event at which scientists talk about developments in their fields to a scientifically literate but non-peer audience drawn from many backgrounds and spanning a wide age range from about 17 to over 80 years. Some 300 presentations form the core of the event. Additional activities aimed at a general public audience and also at young people aged from five upwards attract several thousand participants and give the event something of a festival character. However, its most distinctive feature is the amount of media coverage that it receives, by far the largest for any regular science-based event in the UK. As a consequence it also sees the largest annual gathering of science journalists in the country.

So, in the UK at least, I think we can see the development of science festivals to be rooted in part in a long-standing event. There are many such associations around the world and most of them hold a meeting of some sort. They include the Gesellschaft Deutscher Naturforscher und Ärzte (GDNA), the American Association for the Advancement of Science (AAAS), the Indian Science Congress Association (ISCA) and many more. The AAAS and ISCA both include activities related to young people in association with their meetings. Public Science Day, during which local science centres and other visitor centres open their doors to young people, takes place at the start of the AAAS meeting and a large display of young people's science projects is held at the time of the ISCA congress.

The Edinburgh International Science Festival was launched in 1989. It builds on Edinburgh's reputation as a festival city and has been extremely successful. One of its early achievements was to arrange events in venues which were familiar to the public – galleries, churches, parks, shops – rather than universities and scientific institutions, which the public often finds remote. They also developed workshop-based activities for young people that have become common at events of this kind throughout the UK. Almost 200 000 are reputed to have attended the 1999 festival although it is not clear how many individuals this involves since it represents a count of those attending each event and many people attend more than one.

In March 1994, the UK's first National Week of Science, Engineering and Technology (SET Week) took place. The event is coordinated by the BAAS and has grown impressively. An evaluation of the 1999 week showed that over 400 organizations and institutions organized activities during the week, creating nearly 2 000 events and 9 000 opportunities for people to take part in activities. Over 1.2 million people took part in events and the audience was multiplied many times through media involvement. Unlike the BAAS festival where the main coverage is of science stories, the media mainly reports events in SET Week and actively participates itself by organizing competitions, running special feature articles and commissioning programmes.

I believe that the growth of the UK week is due to four factors:

- central coordination with a 'light touch' that encourages individuals and organizations to arrange activities, rather than one which puts barriers in the way;

- the existence of many organizations in the UK with a commitment to improving public awareness of science which are eager to arrange events;
- strong government support – through the provision of funds for the central coordination, a grant scheme to support some activities and willing participation by ministers and officials in activities;
- strong media interest.

The impact of the week thus becomes greater than the sum of the individual events in isolation and there is a win-win situation for all involved. Event organizers gain more publicity than they would otherwise receive; the BAAS gets applauded for its role and extensive exposure; the Government gets credit for the part it plays and some attractive media opportunities for ministers; and the public gets access to an extensive range of scientists and events.

But are these activities successful? Judging by the numbers of people attending, by the responses of event organizers and participants, and by media coverage, the answer is a resounding ‘yes’. Nonetheless, in spite of these and many other initiatives designed to encourage awareness and appreciation of science in the UK, other indicators provide more equivocal answers. For example, difficulties remain in attracting enough young people of the right quality into courses and careers in science and technology; and the public discussion of public issues on topics such as genetically modified foods and crops seems to be poorly informed, at least as far as an awareness of the scientific issues is concerned.

So what is to be done? John Durant spoke this morning of the need to take the public seriously, to move to a two-way communication process between scientists and the public instead of the one-way process (scientists to public) on which most of our current activities are based. John also spoke of a number of activities that have been designed to reflect such two-way communication, including consensus conferences, deliberative polls and citizens’ juries. But they tend to be few and far between. There is, in my view, a need to develop far more activities that embody this form of communication, which are smaller, localized and cheaper to run. My belief is that science festivals and weeks provide the ideal settings in which such activities can be tried out and that we should make a determined effort to encourage this process to take place.

One of the characteristics of science festivals is that they provide better access for a more general public to science and scientists than other events which tend to attract self-selecting attentive audiences. One of the most successful types of activities of SET Week in the UK has involved scientists putting on displays of their work in shopping centres and talking to the public about what they are doing. This is often a daunting experience for the scientists initially but rewarding once they have got used to it. It suggests to me that conversation skills ought to be included in the menu of communication training courses, helping scientists to talk about their work in the course of casual encounters with others, whether at a shopping centre exhibition, a party or on a train.

I have said that science festivals and weeks can be found locally and nationally, so might there not be an opportunity to give them an international dimension as well? There has been a European Science and Technology Week for some years but, for some reason, it has failed to make a significant impact. In my view this is largely because of the restrictive and somewhat bureaucratic approach to its organization, which is in marked contrast to the more permissive approach we have adopted in the UK. So the challenge to do something more effective internationally is still there. The AAAS has developed its Public Science Day from an activity localized at the venue of its annual meeting to a more national event and has talked about it spreading to other countries. Maybe one positive outcome of this World Conference on Science could be a commitment to develop a world science day, or even a world science week.

Thematic meeting report

István Palugyai
Vice-President, European Union of Science Journalist Associations, Hungary

The aim of this meeting was to examine the possibility of narrowing the gap currently existing between the general public and the scientific community. Raising the level of knowledge within societies is necessary for further scientific and technological revolution. Should this not be fulfilled, the applications of inventions would lead to an increasing number of technological and social catastrophes. We have to face the fact that the rate of scientific and technological development has left the level and rate of social development far behind. The scientific community should be more open towards society. Science has direct and indirect impacts on the daily lives of all people, so scientific literacy is becoming more important for living with democratic rights. What's more, scientific research is introducing changes into our daily lives at an accelerating rate.

The formal education system alone cannot cope with this rapid change, so the media and other informal channels and tools have an increasingly important part to play. The scientific community is aware of the need to popularize science and of the media's crucial social role in informing the public. Science journalists have an important job in helping the public understand the scientific issues at stake in discussions where rhetoric is common and emotions run high. In light of the public's growing need for science news, science journalists must now be more rigorous than ever in deciding what makes a good science story and how to portray its significance accurately. This can be difficult, given the different worlds of science and news media. The best science journalism manages to place new developments in the context of the scientific method as a whole, which is a lot more plodding and ambivalent in its conclusions than can be captured in a headline.

Scientists have to take into account the needs, the previous knowledge and the expectations of their audience. Listening to audiences to get a better understanding of their concerns is an essential part of science communication.

The future of science largely depends on how the general public understands the importance of research. Therefore, scientists have to learn to communicate with the public. The example was given of an Australian model: sessions organized for journalists and scientists. Training in media skills can help overcome the barriers between scientists and journalists. There have been two-day media skill workshops for scientists in Australia over the past seven years. The assessment of the workshops found that most of the media workshop graduates felt that they had better control over their media appearances and that the workshops were helpful for their communication efforts.

The appearance of science in the media is important because there is a major audience interest in science. However, this interest is mainly practical and not theoretical; people would like to orient themselves better in everyday life with the help of science news. Some scientists are gifted teachers and communicators. Perhaps the media can give them more space and opportunity to show the human side of their vocation. There are in journalism new ways to cover science that is relevant to ordinary people. And this kind of science journalism can be found in any section of papers not only the science section. Predominant examples are medical advice programmes on television or articles on current affairs issues like genetically modified potatoes, energy supplied by nuclear plants or environmental issues. The job of a science journalist is not only to translate scientific speech into everyday language but also to look at the context which is of interest to the person in the street.

There is a special importance to popularize science in the developing countries where this knowledge is not a luxury for the few but a necessity for everybody. In these countries, besides the role of governments and public investment in science and technology, there is the essential importance of the activity of the private sector and non-profit institutions.

For two-way communication between the public and the scientific community, there seem to be perfect tools in the shape of more and more widespread science festivals and science days and weeks. They can be seen as a natural development of the multidisciplinary meetings held by associations for the advancement of science and can be adapted to the changing demands of science communication in terms of both the audience and methodology.

There were some suggestions and comments in the meeting as well, for example the following ones:

- More support is needed for events like science festivals or science days/weeks, in order to strengthen two-way communication between the general public and the scientific community. Scientists and journalists should know first the expectations and the educational level of the public. This process should be done both at national and international levels. International organizations should promote or give advice to national authorities (Netherlands).
- The representative of the European Space Agency suggested that the International Space Station (which was due to be launched in November 1999) should be used as a tool for the popularization of science.
- To encourage interaction between scientists and journalists in Sweden there are scholarships for training and workshops for both sides. These have produced excellent results and are offered to other countries as well.

What relationship between scientific and traditional systems of knowledge? Some introductory remarks

Douglas Nakashima
Coastal Regions and Small Islands Unit, UNESCO, Paris, France

Science has become a powerful intellectual institution with a far-reaching and profound influence on our daily lives, our relationship with the environment, our system of values, our world-view. Notwithstanding its prominence in mainstream society, science remains but one knowledge system among many. ‘Other knowledge systems’ embedded in a panoply of cultures and sustaining a broad spectrum of ways of life constitute a rich and diverse intellectual heritage that has begun to attract increasing attention worldwide.

Local knowledge, traditional ecological knowledge (TEK), indigenous knowledge (IK), folk knowledge – various names for these ‘other systems’ have been applied, each with their strengths and weaknesses. ‘Traditional’ underscores knowledge accumulation and transmission through past generations, but obscures the capacity for transformation and adaptation. ‘Indigenous’ reinforces links with indigenous peoples, many of whom harbour particularly strong knowledge systems, but excludes the extensive local knowledge accumulated by peoples with whom the term ‘indigenous’ sits uncomfortably, such as farmers in Africa, herders in Europe or fishers in the North Atlantic.

Whatever name is applied, the fact remains that knowledge systems such as these have guided, and continue to guide, human societies around the globe in their innumerable interactions with the natural world: gathering, hunting, agriculture and husbandry; struggles against disease and injury; innovation of technology and techniques; naming and explanation of natural phenomena; maintenance of equilibria between society and milieu; adaptation to environmental change; and so on and so forth. They represent the dynamic products of an extended history of fine-grained interplay between distinct cultures and specific local environments. This explains their diverse structures and content, their complexity, versatility and pragmatism, and their distinct, internal logic anchored in specific world-views.

What relationship between scientific and ‘other’ knowledge systems? For many biophysical scientists and also the food and drug industry, the first response is to prospect traditional knowledge sets for information useful to science. The potential benefits of this enterprise are multiple: indigenous crop varieties with desirable characteristics; new active agents from traditional medicinal plants; local management techniques co-adapted to local ecosystems. But grave concerns have arisen about the misappropriation of traditional intellectual property, often for economic profit, and a disregard for equitable benefits-sharing with knowledge-holders.

Other scientists promote the integration of scientific and indigenous knowledge, for example in the domain of renewable resource co-management, purportedly blending the best of two world-views. Are such arrangements of mutual benefit? Given inherent imbalances of power in favour of science, how often does scientific cooperation transform into the co-optation of the indigenous system?

These science-centred approaches pose other, more fundamental threats to indigenous knowledge. Indigenous systems possess a cultural logic of their own. When screened on the sole basis of value to science, knowledge judged useful is selected and the remains are discarded as ‘superstition and belief’. Such a process dismembers, debases and destabilizes knowledge systems, jeopardizing their continued existence. By ‘mining’ these systems for short-term intellectual gain, we undermine their very social and cultural foundations and menace the traditional societies that harbour them.

Systems of knowledge: dialogue, relationships and process

Kenneth Ruddle
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The sophisticated local knowledge underpinning many systems of community-based renewable natural resource use and management has been widely demonstrated, especially for agriculture, animal husbandry, forestry and agroforestry, medicine, and marine science and fisheries. Here I describe the main characteristics and 'design principles' of local knowledge systems, with particular reference to coastal-marine fishing communities. As with other bodies of local knowledge, those in coastal societies are empirically based and practically oriented. Most such knowledge combines empirical information on fish behaviour, marine physical environments and fish habitats into comprehensive and frequently complex fish taxonomies, directed towards ensuring regularly successful catches, and, often, long-term sustainment of aquatic resources. In some instances, explicitly conservationist objectives are evident (Ruddle, 1994*a*, 1994*b*).

Local knowledge of tropical marine environments and resources is of great potential practical value in the modern world. It can provide an important information base for local resources management, especially in the tropics where conventionally used data are usually scarce to non-existent, as well as providing a short cut to pinpoint essential scientific research needs. First, however, it must be systematically collected and organized, then evaluated and scientifically verified, before being blended with complementary information derived from Western-based sciences, so as to be useful for resources management (Pauly *et al.*, 1993). But, in addition to these practical aspects, local knowledge is also of fundamental socio-cultural importance to any society because, during knowledge transmission to and the socialization of children over several generations, social institutions are gradually crystallized and social roles become defined.

However, throughout the world local knowledge systems are changing, sometimes rapidly, owing to the pressures of Westernization, urbanization, commercialization and marginalization, among others, as well as to the elitist values often engendered by non-traditional education. In a great many instances, local knowledge is thus either fast disappearing, at worst, or becoming hybridized with extra-local elements. As a reaction, however, and partly related to the resurgence of ethnic pride and indigenous rights movements worldwide, there has been a welcome burgeoning of interest in the subject (Ruddle, 1994*c*).

Common characteristics and design principles of local coastal-marine knowledge systems

There are a number of important commonalities among different corpuses of local knowledge of coastal-marine environments and resources. The principal ones are (Ruddle 1993; 1994*a*):

- they are based on long-term empirical, local observation that is adapted specifically to local conditions, embraces local variation and is often extremely detailed;
- they are practical and behaviour oriented, focusing on important resource types and species;
- they are structured, which makes them somewhat compatible with Western biological and ecological concepts through a clear awareness of ecological links and notions of resource conservation;
- they are often dynamic systems capable of incorporating an awareness of ecological perturbations and of merging this awareness with an indigenous core of knowledge.

More specifically, certain structural and procedural characteristics of local knowledge systems are evident from examples around the world. These are:

- there exist specific age divisions for task training in economic activities;
- different tasks are taught by adults in a similar and systematic manner;
- within a particular task complex (e.g. gill-netting) individual tasks are taught in a sequence ranging from simple to complex;
- tasks are age and gender specific and are taught by members of the appropriate sex;
- tasks are site-specific and are taught in the types of locations where they are to be performed;
- fixed periods are specifically set aside for teaching;
- tasks are taught by particular kinsfolk, usually one of the learner's parents;
- a form of reward or punishment is associated with certain tasks or task complexes.

Components of local marine knowledge

- *Fish behaviour:* the main component of local ecological knowledge of marine resources concerns the behaviour of fish and other animals, particularly for species of principal economic and ritual importance.

- *Marine physical environments and fish habitats:* knowledge of the marine physical environment is of major importance to both the fishing technologies employed and to the targeting of fish by species.
- *Local knowledge and ecosystems concepts:* in some societies bodies of local knowledge of coastal-marine systems demonstrate a sophisticated understanding of local marine ecology, the behaviour of marine fauna, and of the interrelationships among the organisms involved and elements of the physical environment (Ruddle, 1994*a*).

The functions of local knowledge

Social role

Local knowledge assumes a pivotal role in any community: integration of an institutional order is understandable only in terms of the 'knowledge' that its members have and share of it. Such knowledge underlies institutionalized conduct and defines its areas, as well as both defining and constructing the roles played by individuals in the context of institutions. By definition, then, it also controls and predicts all conduct by the operators of a resource system. Since such knowledge comprises a body of generally valid truths about reality, any deviance from the social order is a departure from reality.

Modern practical usefulness

Owing largely to disparagement, the practical usefulness of local knowledge is rarely used to assist the design of development projects or management systems. Interrelated economic, ideological and institutional factors still combine to perpetuate the marginalization and neglect of local knowledge and, therefore, of participatory approaches to development and management (Ruddle, 1994*b*).

The principal areas in which modern fisheries science is deficient and where traditional fishers can contribute complementary local knowledge to development and management planners are (Ruddle, 1994*a*):

- *traditional management methods:* traditional common property systems of inshore fisheries management occur throughout the world and often ensure equitable access and management measures that include limited entry; seasonal, spatial, gear, size, or species restrictions; appropriation rights; and the concept of community-based sole ownership;
- *conservation:* many such systems include deliberate conservation measures, such as the widespread use of closed seasons and areas and harvestable size limitations;
- *stock assessments:* local knowledge often provides a useful basis for understanding local fish stocks and their population dynamics (especially about the timing, location and behaviour of spawning aggregations of reef and lagoon fishes);
- *environmental impact assessment:* local knowledge of spawning migrations and spawning aggregation sites indicates the likely impact of coastal engineering projects;
- *local hydrography:* local knowledge is often rich in information on water qualities and physical behaviour;
- *mapping:* local knowledge of living coastal resources also includes an intimate spatial familiarity with the physical environment, including local currents, seabed conditions and other such phenomena;
- *fishing methods and technologies:* the indigenous knowledge expressed in fishing methods and technologies affords an alternative to high-technology development approaches. Further, the knowledge of fish behaviour on which traditional methods of fishing are predicated can be adapted to the use of modern technology;
- *fish systematics and biology:* local fish names and the taxonomies they imply, as well as empirical knowledge behaviour often embodied in local nomenclature, can be of immense practical usefulness.

Gender issues in local knowledge

Local knowledge is 'gendered' (Warren, 1989) because men and women usually have different and often complementary economically productive roles, different resource bases and face different sets of social constraints. If this is not comprehended and integrated into general local knowledge, the understanding of fisheries management systems will be seriously deficient and the consequences of this for the formulation of 'development' and 'assistance' projects often disastrous (Nauen, 1989). Both consideration of logical structures of total systems of local knowledge and an awareness of gender and age roles in rural society make it self-evident that gender considerations are important in understanding local knowledge in fishing communities.

There are at least main four types of gender difference in local knowledge systems men and women having (Norem *et al.*, 1989):

- different knowledge about similar things;
- knowledge of different things;
- different ways of organizing knowledge;
- different ways of preserving and transmitting knowledge.

Continuity and adaptation of local knowledge

Through contact with the greater society beyond a small community, local knowledge can become delegitimized and lost entirely, or contact can result in the hybridizing of local knowledge with extra-local elements. Five overlapping categories of response to this process may exist among rural people (Thrupp, 1988):

- increased pride in their local knowledge and methods;
- openly expressed rejection of Western innovations and related knowledge as disruptive of local knowledge and resource management;
- scepticism of introductions but hesitancy to express it;
- embarrassment and shame regarding their local knowledge and techniques;
- idolization of the introduction, and concomitant rejection, of local knowledge and techniques.

Factors causing change in local knowledge systems

Traditional community-based marine resource management systems and their knowledge systems are affected by external factors that cause stresses and often lead to radical change in systems, including their demise. This is not new; but the intensity of impacts and the diversity of their sources has increased. Among the principal, all-pervasive external forces are the legacy of colonialism, contemporary government policy and legal change, the replacement of traditional local authority, demographic change, urbanization, changes in education systems, modernization and economic development, commercialization and commoditization of living aquatic resources, technological change, the policies of external assistance agencies, and national policies for economic sectors other than fisheries (Ruddle, 1994*c*). Such external forces rarely act in isolation but rather as a mutually reinforcing and potentially destructive complex. Traditional systems decline under pressures exerted by both internal and external sources, and the latter can trigger the former, such that local phenomena may mask deeper-seated problems afflicting social institutions. Community institutions and local knowledge and management systems are not immutable: they are dynamic, adapting to external as well as internal and local experiences and pressures. Such systems are dynamic, historically conditioned and deeply embedded in larger political, economic and social realms.

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Indigenous knowledge and conservation policy: aboriginal fire management of protected areas

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The territories of indigenous peoples are often targeted for government conservation initiatives because of their exceptional biodiversity. Causal links between indigenous occupation and the maintenance of biodiversity, however, are hardly considered, and only on very rare occasions has indigenous knowledge and practice been integrated into official conservation policy. One such exceptional case concerns the Aboriginal peoples and their use of fire for landscape management. Today, this ancient practice is being reinstated by national and state authorities as the primary management tool for an increasing number of protected areas in Australia.

Fire has played a significant role in the shaping of the Australian landmass and its biota. It is an ancient elemental force, constructed as a powerful cultural and religious symbol by Aboriginal peoples in Australia, and a key tool for the reproduction of landscapes, particularly in northern Australia. Since the arrival of settler Australians and their confrontation with the 'burning rage' of the Australian landscape, fear of wildfire has motivated a repression of Aboriginal burning practices in most parts of Australia. Researchers from the Aboriginal domain have nevertheless been able to report during the 1970s and 1980s on the continuance of traditional Aboriginal burning regimes and their impact on the landscape. Current understanding of these seasonal fire management traditions is that they permit reproduction of fire-dependent floral species and, through the creation of buffer zones, protect fire-intolerant floral communities such as monsoon forests.

For these landscape mosaics in remote Australia, the most significant disruptive factor during the colonial era and during much of the 20th century has been the removal of Aboriginal societies, whether by violence, forced removal or enticement of small groups to move to government settlements. The absence of traditional groups to carry out the annual and seasonal mosaic burns has turned some of these areas into 'the new wilderness' described by Bowman: areas where wildfires, fuelled by accumulated grasses and undergrowth, cause extensive damage.

During the last decade, federal national park authorities and some state authorities have developed policies for reproducing Aboriginal fire management practices in order to maintain the landscapes of the wet-dry tropics and the arid zone. In a few cases, these efforts have been carried out in collaboration with the traditional Aboriginal owners of the relevant areas.

Some of the key social and policy issues arising from these new developments include the dissonance between Aboriginal and park administration responses to fire management in such areas and the alteration of landscapes by large grazing animals, such as buffaloes. In the future, Aboriginal approaches to reintroducing Aboriginal traditional methods may be more successful. In the words of Yibarbuk (1998), 'fire must be managed and people must be on their country to manage that fire'.

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Les savoirs agricoles traditionnels dans la production vivrière en Afrique subsaharienne

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Les savoirs agricoles en Afrique au Sud du Sahara n'ont pas la même renommée que les savoirs médicaux. Ils ne tirent d'ailleurs l'essentiel de leur prestige relatif que de leur contribution à la protection de l'environnement. Les contributions majeures dans ce sens, sont fondées sur les études relatives à la culture du riz et aux méthodes de gestion écologique du terroir (Richards, 1985, 1986).

Les « savoirs locaux » ou plus précisément, les « savoirs localisés » agricoles constituent cependant la principale source de savoirs des paysan(ne)s pauvres et des « petit(e)s » paysan(ne)s, soit 70 % à 90 % des producteurs agricoles et plus de 60 % des populations vivant en Afrique au sud du Sahara. Les dysfonctionnements qui interviennent dans la production et la diffusion de ces savoirs constituent des atteintes majeures au système de production agricole des populations et du coup à l'équilibre alimentaire des pays africains au Sud du Sahara.

Les « savoirs locaux » font, depuis les années 1980, l'objet d'un regain d'intérêt scientifique. Les sciences sociales, notamment l'anthropologie et la sociologie, ont découvert de nouveau la problématique des savoirs indigènes, dans le sillage des études sur le développement durable, mais aussi sur les processus de transformations sociales et la modernité (Elwert, 1995; Séhouéto, 1996). Je voudrais insister sur la nécessité de placer les recherches et la réflexion sur les savoirs dits traditionnels / indigènes / locaux / endogènes, etc. en Afrique, au coeur des études sur la modernité africaine, comme l'un des types idéaux de modes de transformation des sociétés africaines. Ils s'inscrivent dans le courant de ce que le sociologue berlinois Georg Elwert appelle les « autres modernisations », c'est à dire, les modes par lesquels les peuples non européens assurent et assument leur auto-transformation, à travers la résolution des problèmes (identifiés par eux comme tels) et dont ils élaborent les solutions à partir de leurs ressources ou modalités propres. Par cette fenêtre, la problématique des « savoirs locaux » recevrait une meilleure attention et s'intégrerait mieux dans les préoccupations de développement.

De quels savoirs est-il question, lorsque je parle de « savoirs localisés » (au lieu de « savoirs locaux ») ?

Mon histoire personnelle – je suis originaire de la côte des esclaves du Bénin, ancienne colonie française, où l'élite pense d'abord Paris, avant Lagos ou Lomé, – m'a conduit à prendre de la distance avec le terme « indigène » à cause de la charge historique dévalorisante qu'il véhicule.

Les termes « locaux » et « endogènes » portent aussi quelques risques de (més)interprétation :

- il ne s'agit pas d'un stock plus ou moins routinier et statique. Il s'agit plutôt d'un corpus dynamique, continuellement renouvelé, peu systématisé, identifiable par le croisement des discours paysans sur les pratiques agricoles et les décisions concrètes que prennent quotidiennement les paysan(ne)s ;
- il ne s'agit pas toujours d'un pur produit du génie d'une localité ou d'un peuple spécifique. Sont constitutifs des savoirs, diverses combinaisons issues des adoptions, démantèlements, détournements et expérimentations plus ou moins originales de divers savoirs.

Ces savoirs se conservent difficilement sur une longue durée, sauf à travers divers modes d'encapsulation culturelles ou religieuses.

Le terme « savoir populaire » pourrait induire aussi en erreur, sur les plans conceptuel et méthodologique avec des conséquences majeures sur les résultats de recherche. Au plan conceptuel et méthodologique, je prends en effet de la distance vis à vis du « populisme idéologique » qui, en faisant l'économie d'un examen rigoureux des données empiriques disponibles, « valorise systématiquement les 'savoirs populaires', les idéalise et finalement les fétichise » (de Sardan *et al.*, 1990). Une attitude critique implique cependant un « populisme méthodologique », qui « part de l'hypothèse que les acteurs de base sont dotés de ressources (politiques, techniques, cognitives, interprétatives) et ne se caractérisent pas à priori par l'absence ou le manque de compétences, de services, de techniques » (de Sardan *et al.*, 1990). Mieux, l'analyse des données empiriques que j'ai recueillies jusqu'ici ne me permet pas de confondre les savoirs traditionnels aux représentations collectives que possède tout individu régulièrement socialisé peu ou prou. Dans les sociétés fon ou lokpa (respectivement au sud et au nord-ouest du Bénin), il existe des personnes précises qui se distinguent des autres de part leur contribution plus active dans la production, la conservation ou la diffusion des savoirs. L'histoire de l'émergence de telle ou telle variété ou technique de culture permet – autant que l'oralité le permet – de situer des auteurs précis. Les savoirs traditionnels sont bien souvent des savoirs spécialisés, complexes, socialement répartis de façon inégalitaire et dont la diffusion peut s'expliquer de manière fructueuse à partir des catégories de l'anthropologie économique (prestation, contre-prestation, mise en commun, redistribution, réciprocité, échanges marchands).

En proposant le terme « savoir localisé », je voudrais :

- distinguer ces savoirs des produits du système conventionnel d'origine coloniale de recherche agricole, sans les opposer : les champs expérimentaux et les stations de recherches coloniales constituent l'une des sources constitutives des savoirs traditionnels. Le vol des espèces en expérimentation constitue d'ailleurs l'une des sources de diffusion desdites variétés (Elwert *et al.*, 1989; von der Lühe, 1991; Séhouéto, 1996) ;
- introduire une approche opératoire qui permette d'évaluer les termes et les modes de « localisation » des savoirs : émergence à travers l'expérience et l'expérimentation, encapsulation culturelle ou religieuse, négociation sociale du contenu et de la forme des savoirs, diffusion suivant des modalités économiques, etc. Bref, insister sur le fait que, dans le domaine agricole, les paysan(ne)s produisent et / ou adoptent continuellement de nouveaux savoirs qu'ils soumettent, dans leur expression et dans leur diffusion, à des schèmes cognitifs et culturels spécifiques, à des logiques sociales propres.

L'inévitable médiation culturelle ou religieuse dans l'expression et la diffusion des savoirs cachent bien souvent les dimensions expérimentales et positives des savoirs paysans. L'encapsulation des savoirs dans des schèmes cognitifs et culturels propres aux peuples d'où émanent les acteurs sociaux qui les ont produits – interdits, tabous, divers signes rhétoriques, cosmo-sociologiques – relève de la normalité de la science elle-même (Latour et Woolgar, 1979). On ne devrait donc pas s'y méprendre et réduire ces savoirs à des reliques du passé, au folklore et au merveilleux, bon pour les livres de contes pour enfants.

En guise de conclusion

Une certaine connaissance des savoirs localisés impose du coup des tâches fondamentales, tant au plan scientifique que politique. Ces tâches consisteront fondamentalement à faire justice à ces savoirs qui font vivre l'écrasante majorité des Africains au sud du Sahara.

En ramenant mes propos à la dimension des savoirs agricoles, il convient de tirer des conséquences pratiques de ce que les lourdes machineries de recherches agronomiques profitent pour le moment aux chercheurs et à quelques grands entrepreneurs agricoles. Il est souhaitable et juste de considérer les savoirs agricoles des petit(e)s paysan(ne)s comme la base essentielle d'une agriculture durable en Afrique noire, au double plan social et écologique. La modalité pratique d'un tel agenda se trouve dans une collaboration (difficile, mais possible) entre chercheurs de type « occidental » et paysan(ne)s, pour identifier des sujets de préoccupation et conduire les recherches appropriées, dans le respect réciproque. La valorisation de ces savoirs passent aussi forcément par la réforme des modalités de reconnaissance de la propriété intellectuelle.

Il s'agit, en outre, de constituer un discours critique sur les savoirs dit « traditionnels », « locaux » ou « localisés », en faisant de ces savoirs un objet spécifique de recherches scientifiques d'enseignement universitaire et de recherches. Ainsi, émergera-t-il un espace public spécifique de ces savoirs, sans lequel une communauté scientifique véritable ne semble pas envisageable.

Autrement dit, il ne s'agit pas d'intégrer les savoirs locaux dans les efforts de développement, comme par générosité : ils y sont déjà. Il s'agit d'en prendre acte et d'en déduire des mesures équitables. Il s'agit de partir de ces savoirs, créer les espaces publics et les discours publics sans lesquels ils resteront résolument emprisonnés dans le folklorique, l'anecdotique, les merveilles du passé. Il s'agit pour le discours scientifique de s'imposer de nouveaux instruments théoriques et méthodologiques en vue de rendre plus rigoureuse sa description, sa compréhension et son interprétation des savoirs localisés : il jetterait ainsi le pont entre ces savoirs et la recherche conventionnelle. Ce discours scientifique se fera utile pour la minorité des « développeurs » qui osent se poser des questions nouvelles, à partir des expériences des paysans. Il contribuera à promouvoir ces autres savoirs, peu utiles pour les industrie agro-alimentaires et les grandes places de cotation, mais qui font vivre la majorité des humains au sud du Sahara.

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Improving health care by coupling indigenous and modern medical knowledge: the scientific bases of Highland Maya herbal medicine in Chiapas, Mexico

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With the exception of the well-developed traditions of medicine in Asia and India, the medical ethnobiological knowledge of traditional peoples elsewhere in the world has not been sufficiently recognized. 'Folk medicine' is often seen as exotic, magical and based on simple superstitions.

The medical ethnobiology of the Tzeltal and Tzotzil puts forward evidence that strongly supports the scientific bases of traditional medicine. Efforts to develop innovative and effective health maintenance programmes should include as a fundamental component the selection of medicinal plant species used by the Tzeltal and Tzotzil to treat illnesses. The Tzeltal and Tzotzil Maya of the Highlands of Chiapas, Mexico, recognize more than 250 classes of health conditions that can be grouped into about 20 major classes. These conditions are treated by a remarkable pharmacopoeia that includes more than 1 600 medicinal plants species, although only about 600 of these species occur as widespread herbal remedies throughout the Chiapas Highlands. Of the recognized major afflictions, eight major classes account for 80% of all of the medicinal use reports associated with the 204 most commonly used medicinal plant species. These eight major health conditions are gastro-intestinal diseases, dermatological infections, respiratory conditions, wounds resulting from accidental injuries and violent acts, broken bones and sprains, fevers, infections of the teeth and mouth, and eye infections.

Focusing on those species on which both Tzeltal and Tzotzil strongly concur as to their primary use, we have isolated a small set of around 50 medicinal plants that target particular illnesses in the eight major illness classes. With a single exception, these species are mutually exclusive as to their use in the treatment of individual conditions. Thus, it is apparent that the Maya have discovered plant species that are highly effective in reducing the symptoms associated with individual health conditions. In their totality, these critical species form what is referred to in Mexico as the *cuadro básico* or 'basic core' of the Highland Maya ethnopharmacopoeia. These medicinal plants are those that represent what might be called the Mayas' 'herbal medicine kit', one comprised of just those most commonly known and most effective medicinal plants used in the treatment of the most significant health problems. Furthermore, initial laboratory bioassay analyses of these species confirm that almost all show strong bio-activity that is likely to be responsible for their presumed efficacy.

In order to promote the use of the Highland Maya *cuadro básico* as part of a programme to improve their quality of life it must be noted first that, in traditional Highland Maya herbal medicine, one exclusively employs fresh plant material in the production of herbal remedies. Furthermore, none of the *cuadro básico* species, nor the large majority of all other medicinal herbs, are typically cultivated in home gardens.

We have recently developed a pilot project in collaboration with El Colegio de la Frontera Sur which aims to carry out horticultural experiments with each of the 50 *cuadro básico* species to determine their horticultural potential as cultivated plants. This horticultural experimentation will be accompanied by in-depth cross-regional study of the ecology of these plants as well as ethnobotanical surveys documenting cultural variation in preparation, required admixtures and standard dosage. The goal will be to develop culturally appropriate horticultural procedures leading to the low-cost production of herbal remedies that requires little in the way of intensive labour input.

Our research group has signed collaborative agreements with three Highland Maya communities to establish communal medicinal plants gardens. Each garden, measuring 625m², now includes more than 150 distinct medicinal plant species, many of them part of the *cuadro básico* inventory. In return for technical and scientific consultation, each community must maintain their gardens in good condition, record and update information on included species and provide systematic instruction to younger Maya on traditional knowledge of the classification and cultural importance of each species.

To complement this horticultural experimentation there will be the development of *cuadro básico* workshops conducted by Maya collaborators in local municipal centres and in selected communities where Maya health promoters have already requested our services as consultants on traditional herbal medicine. One such workshop has been completed and was successfully accepted by the community. One result of the workshop was the establishment of a local community medicinal plants garden to be maintained under the same conditions as our previous garden experiments.

The promotion of the general use of a *cuadro básico* of the most important medicinal plants builds naturally on the highly refined empirical ethnomedical knowledge base of the Highland Maya. Our pilot research proposes that the primitive primary health care available to Maya Indians in rural Chiapas can be greatly improved by widespread use of pharmacologically active medicinal plants, especially if these species can be made readily available as cultivated plants produced in local ethnobotanical gardens. Furthermore, the active promotion and preservation of this knowledge would be highly cost-effective in areas where the delivery of modern medications is economically impossible. Such actions would also contribute to a wider recognition of the intrinsic value of Highland Maya ethnobiological knowledge.

Educating today's youth in indigenous ecological knowledge: new paths for traditional ways

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I am an elder from an indigenous nation of subarctic Canada, the Eeyou or Cree Indians of the James Bay region. One of our great concerns is what the future will hold for our children and youth. As for many indigenous peoples around the world, our territories and our ways of life are undergoing processes of change and renewal. For the Eeyou, education and the transmission of knowledge is a critical issue but a complex one. On the one hand, we understand that education in non-indigenous ways may allow our children to live well in a world different from the one we grew up in. At the same time, we also profoundly believe that Eeyou youth must sustain their indigenous knowledge and ways, as it is only by knowing from where they come that they will be able to determine where they wish to go.

But passing on traditional Eeyou knowledge in today's world is not an easy task. There are many barriers to overcome. In the past, Eeyou children of the Chisasibi community were born out on the land. Today, the children are born in hospitals and grow up in the town. They are educated differently than their forefathers, receiving formal schooling, and they do not have the connection with the land that past generations had.

Even many parents today find it difficult to pass on Eeyou culture and tradition to their children, for when they were young they were subjected to government programmes of assimilation through residential schools. The residential schools cut the ties between children and their parents and grandparents by retaining the children in the school and in the community during their formative years. They were not allowed to stay with their families for more than six weeks each year. From the late 1940s to the mid-1970s, Eeyou culture and language were forbidden in the schools. This period of residential schools created a gap in the transmission of Eeyou culture and knowledge.

Since the 1970s my community has also suffered greatly from major changes brought on by large-scale industrial development on our traditional hunting territories[1]. For any society, rapid environmental and social change is disorienting and potentially destructive. In my own community of Chisasibi, the human toll has been high and children and youth have suffered greatly. Family violence, juvenile delinquency, alcohol and drug abuse, depression and suicide ... this is the disturbing legacy 'borne by our youth'.

For these young people who have dropped out of school and turned their backs on society, Eeyou elders, along with our Cree Hunters and Trappers Association, have set in place a kind of 'bush school'. Young boys and girls, often from families who have not been able to offer the necessary guidance and support, are taken out to traditional hunting and trapping territories by an elder hunter and his wife. There, away from town life, they learn to live according to another rhythm and set of values. Through a process of apprenticeship, they begin to appreciate the knowledge and practices by which Eeyou have lived on the land. The youth acquire knowledge that has been passed down to the elders, knowledge that is based on thousands of years of intimate experiences and interaction with the land, the waters, the animals, the plant life and the skies of the subarctic region.

This traditional knowledge cannot be taught in the classroom. For many years now, the Cree School Board has included culture courses in its formal school curriculum. Children are exposed to Eeyou culture through the making of traditional objects such as moccasins, sledges and snowshoes, and through lectures on their use. But in my opinion, young people cannot be taught how to hunt, how to trap and how to survive on the land through lectures and diagrams.

To pass on traditional knowledge, there is no better classroom than the bush. Young people, who have been taught Cree culture in school, often come to me and plead to be taken out in the bush. Our innovative 'bush schools' are somewhat of a hybrid between traditional learning and formal education. With a curriculum specially adapted to bush life, they offer an apprenticeship which includes both hunting and fishing knowledge and Eeyou spirituality. The bush school enables Eeyou youth to better understand their heritage by getting them out on to the land and allowing them to discover for themselves what Eeyou culture is and what it means to them as individuals.

Many youth who are sent to the bush schools are not just regular students. They are the ones who are deemed to be misfits or lost. They are labelled incorrigible, abusing alcohol and drugs, and straining relationships to the limit, including those with their immediate families. They have been rejected by the schools and by the community. Of course, these young people cannot just be taken out on the land and immediately taught traditional knowledge, for often this is one of the things that they are rejecting. The habitual dynamic of teacher-student must be replaced by another relationship.

Out on the land, young people are given a fresh start. Their past problems or crimes are not mentioned so as not to embarrass them. They are received like a member of the family and the teaching and learning process evolves quickly in an atmosphere of caring and sharing. I have to get to know them, know how their minds work, learn how their feelings and emotions help or prevent them from learning or accepting themselves. Everyone is included in the teaching and learning process, for the Eeyou believe that even children have something to teach or share with the elders. In many instances, I become the student and they the teachers.

I will start out by teaching them about respect, not just for the land and others, but also for themselves. They must learn to be proud of themselves. The knowledge of the Eeyou

Nation is based on a solid foundation of respect. We believe that humans are not separate from anything, not from the land, not from the animals, not from the seas and the skies, and certainly not from each other. We are all one family, children of the Creator, even if we live, pray and understand in different ways. We are linked by common dreams of peace, compassion, harmony, truth, integrity, wisdom, knowledge and, most of all, love. Traditional Eeyou knowledge teaches that the Creator made all humans equal and it was not in the Creator's plan that one colour of man should oppress another, whether through slavery, economic or any other form of domination. Traditional teachings extend this belief to the animal kingdom. For example, it is believed that humans were not put on this Earth to destroy the land or the animals but to protect and ensure their survival for future generations.

I use several different methods to pass on knowledge to the young people when they are out on the land. One method which has been used for countless generations is legend and story-telling. The youth will ask questions about the meaning of the legend and I will tell them the meaning so that they may understand for themselves what is meant by Eeyou culture.

Another way of passing on traditional knowledge is to take the youth out on the land and to familiarize them with the landscape. When young people come into the camp, they must be taught how to talk about the land. They learn new words in their own language so that they can describe the shape of a lake, a line of trees crossing a landscape or a passage between hills. In town, part of the Eeyou vocabulary is lost because it is no longer used or applicable and English words infiltrate Eeyou vocabulary. For example, the vocabulary used inland differs from the vocabulary used on the coast (the village of Chisasibi is located on the coast). For example, they must know that the word for a bay on a lake, *yadowaganee*, is different from the word for a bay on the ocean, *awasach*. The same distinction is made for a point of land. If it is along the sea coast, it is called amid *stawayach*, but on a lake it is named *minawadem*.

The young people must learn this special vocabulary in order to understand when an Elder gives directions. They are taught how to get to and recognize places, even though they have never been there before. Once they have developed their survival capacities, they are sent out to navigate on the land on their own. In this way, they learn about the land, the words they need, the basic skills to survive… by actively doing and learning through doing.

The youth are taught how to live off the land, how to choose the right kind of firewood, how to set up camp if they are caught outside for the night and so on. They stay with me and my wife in our tepee and learn how to take care of themselves. The girls learn how to clean a tepee and how to keep the tepee stocked with water and how to handle an axe for chopping firewood. The girls will also learn how to skin and clean the different animals. My wife will also teach the young girls how to look after themselves and their bodies. The boys will learn the different traditional techniques for hunting such as how to set a rabbit-snare. First they are shown how, then they must act on their own.

These traditional methods of teaching and the long stay out in the bush seem to have an effect on the Eeyou youth. Sometimes a parent will call me to ask what happened out on the land. They will comment that their child now enjoys sharing the workload or that he has begun to enjoy different activities. The parent is glad that the child doesn't pass his days away sleeping. While the programme in the bush lasts only for a period of three to four months, I keep contact with the child afterwards. Often I will check up on an individual at school and the news is mostly good. The child has a renewed interest in learning.

In the changing world in which we live today one knowledge system should not be favoured over another. It is essential for traditional knowledge to be passed on, but it is wrong to think that this transmission can be done in the same way as scientific knowledge. Our youth require both scientific knowledge from outside, as well as their own traditional knowledge. But each of these sets of knowledge is passed on in a different way and has its own place for teaching. Formal education can happen in the classroom, but traditional knowledge must be passed on to our youth out on the land where our people have always hunted, fished and trapped. To ensure the continuing survival of our traditional knowledge, we must develop pathways which are parallel and complementary to formal education.

Note

1. Since the 1970s the Cree Nations of east James Bay, and in particular that of Chisasibi, have been confronted with major environmental and social transformations due to the construction of a series of hydroelectric mega-projects.

Thematic meeting report

Douglas Nakashima
Coastal Regions and Small Islands Unit, UNESCO, Paris, France

Sophisticated and detailed knowledge of the biophysical environment is not confined to science. Societies from all regions of the world have developed rich sets of experience, understanding and explanation relating to the natural world. Often dismissed by scientists as irrational and insignificant, these 'other systems of knowledge' in fact provide much of the world's population, including the most impoverished and marginalized, with the principal means by which they fulfil their basic needs. Furthermore, these traditional knowledge systems, rooted in other cultures, are expressions of other ways of living in the world, other relationships between society and nature, and other approaches to the acquisition and construction of knowledge. As such, they harbour knowledge as yet unknown to science and potential options for sustainable livelihoods that are of benefit to all humankind. This thematic meeting was organized to consider these traditional or local systems of knowledge and their interrelationships with mainstream science and society.

In his brief opening statement, the Chair, Dr B.V. Subbarayappa, emphasized the rational nature of traditional knowledge systems, each operating within its own epistemological framework. As these knowledge systems provide us with an integrated vision of the relationships of the individual to society and of humankind to the natural milieu, their relevance is greater than ever before.

The meeting continued with a series of five presentations concerning distinct cultural groups, regions and issues. Professor K. Ruddle (Kwansei Gakuin University, Japan) reviewed current understandings of traditional knowledge systems, underlining their pragmatic focus, grounding in local phenomena, internal structure, inherent dynamism and modes of transmission. Providing examples from his research among tropical coastal fishing peoples of the Asia-Pacific region, he emphasized the importance of the distinct knowledge sets held by women, as well as by youth. He called for a 'fresh approach' that would avoid the pitfalls of romanticizing traditional knowledge (as misguided as its denigration), while exposing at the same time the contribution of 'magic and serendipity' to the practice of science.

Professor M. Langton (Northern Territory University, Australia) outlined current heated debates over the role of Aboriginal fire strategies in shaping Australian landscapes. She described the joint Aboriginal-state management structures put into place in four National Parks in northern Australia, where traditional fire regimes have been adopted as tools for maintaining ecological mosaics and conserving biodiversity. Within these protected areas, the concordance among, and conflicts between, traditional knowledge and practice, biodiversity conservation, recreation, ranching and mining raise a number of contentious and challenging issues.

Pointing out that traditional or 'localized' agricultural knowledge continues to feed some 60% of sub-Saharan Africa, Dr L. Séhouéto (Institut Kilimandjaro, Bénin) exposed the fallacy of dismissing traditional knowledge as marginal. For small-scale farmers, who represent the vast majority of Africa's populace, traditional knowledge provides for the major part of their needs, whereas science remains confined to a privileged circle of researchers in universities and research centres, along with a handful of large-scale agricultural entrepreneurs. Accordingly, sustainable agriculture initiatives must be based upon the traditional knowledge of small-scale farmers in order to succeed, and analyses of social transformations in African society must factor in traditional knowledge. Given the social complexity of knowledge systems (e.g. unequal knowledge distribution and the importance of knowledge specialists), Dr Séhouéto emphasized the need for a more rigorous understanding and interpretation of traditional knowledge, in order to bridge the gap between 'other systems of knowledge' and conventional research.

Professor B. Berlin (University of Georgia, USA) presented results from his work on the medical ethnobiology of the Highland Maya of Chiapas, Mexico. Among the Maya, the most commonly occurring and most significant illnesses are treated by a limited set of medicinal plant species, with little overlap in the species used for treating particular conditions. Laboratory evaluations of these species reveal their high pharmacological efficacy, confirming the therapeutic value of this indigenous herbal medicine. On this basis, actions are continuing to provide greater recognition and stem the erosion of Maya ethnobiological knowledge, while offering improved and cost-effective health maintenance programmes for these remote locations.

In the final presentation, Mr Robbie Mathew, a Cree Indian elder (James Bay, Canada), spoke of his long experience passing down traditional Cree knowledge and values to youth. Despite the establishment of a Cree school commission and courses in Cree culture, Mr Mathew made clear that the knowledge of indigenous people could not be transmitted in the classroom. Only when young people are taken out on the land do they gain a meaningful understanding of Cree ways and an opportunity to put them into practice. But traditional knowledge is not just information and techniques. Having 'hosted' on his hunting territory many Cree youth who have rejected and been rejected by school and community, he underlined the vital links between traditional knowledge and spirituality that have allowed these troubled youth to find their own way back to a life in balance.

Discussion

More than 50 delegates attended the event and their questions, comments and debates considerably prolonged the meeting. Almost without exception, the participants acknowledged that traditional knowledge is a vital heritage for humanity. They recognized that, for the great majority of the world's population and in particular for those living in developing countries, traditional knowledge provides the principal means of fulfilling basic needs with respect to food, water, shelter and medicine. Delegates from East and West Africa, for example, underlined the continuing importance of traditional healers, who provide for 70-80% of the population. Accordingly, it is on the basis of a people's own knowledge system and through their evaluation of its strengths and weaknesses that sustainable options for development should eventually be found.

A number of delegates argued for the recognition and designation of traditional knowledge as 'science', pointing to its proven track record (e.g. the traditional origins of many commercial drugs, such as aspirin, quinine, etc.) and parallels with scientific methods (demonstrated use of empiricism, experimentation, deduction). Other individuals, however, argued for the need to differentiate scientific from traditional knowledge. The Cartesian separation of 'mind' from 'body', 'belief' from 'validated truth' was portrayed as a unique feature of science that preconditioned significant scientific discoveries in several domains. Nevertheless, it was acknowledged that science and local knowledge remain on an equal footing when confronted with complex processes such as ecological systems and, in these domains, bridges should be built between the two. Despite these differing views on the status of traditional knowledge with respect to science, there was general agreement that traditional knowledge remains an invaluable resource for scientists and traditional societies, and that it deserves broader recognition and active protection.

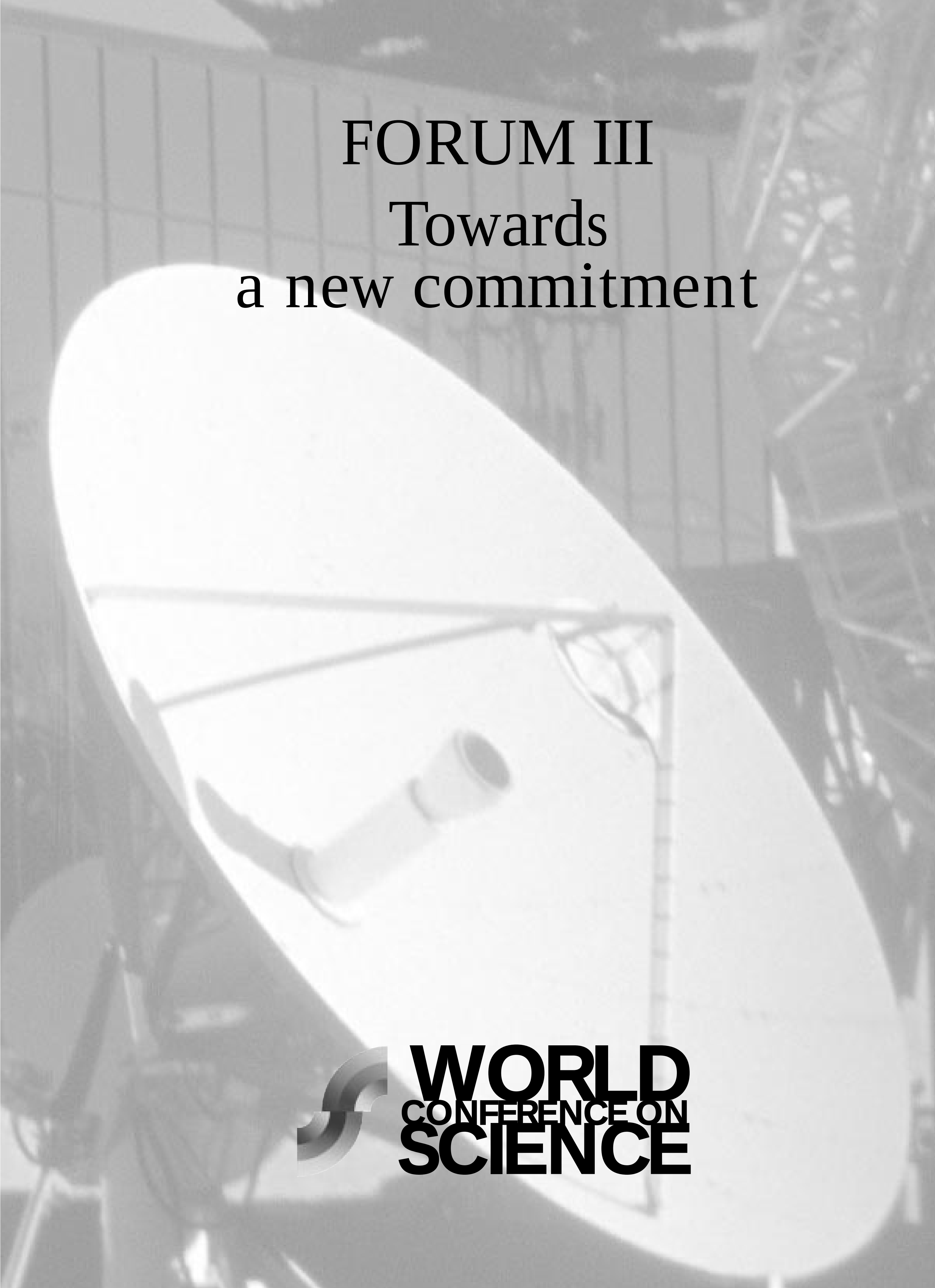
Some strongly divergent views were expressed during the discussion. One delegate completely dismissed traditional knowledge as unworthy of serious attention from scientists, though his presentation of examples from para-science (studies of 'remote-viewing') suggested a limited understanding of the topic. His intervention provoked another delegate to declare that it is time to overcome our ethnocentric tendency 'to take ourselves as the centre of the world'. In his opinion many world-views coexist and scientists must learn to accept that 'science is just one belief system', albeit a particularly strong and dominant one, among many.

Several persons expressed concern about the continuing erosion and loss of traditional knowledge and the need to provide support to the societies that hold this knowledge. In East Africa, the evangelistic work of Christian missionaries was seen as one significant threat, while others made mention of the problems caused by formal education. Indeed, after several years of schooling, indigenous children learn to disrespect their own traditions and despise their own elders. Accordingly, one significant goal is to better comprehend the transmission of traditional knowledge in order to take relevant actions to ensure its perpetuation as a living and dynamic human endeavour. In many circumstances, such actions will require a concerted effort to restore understanding, respect and pride, especially among youth, for their own traditional knowledge systems.

The vital link between traditional knowledge and traditional land was also underlined. Environmental degradation was reported to be an important factor contributing to the erosion of traditional knowledge. Similarly, the traditional knowledge of many indigenous groups is threatened by their limited or precarious access to ancestral lands. Accordingly, it was pointed out that the defence of their knowledge must go hand in hand with the recognition of their claims for land.

Several actions in support of traditional knowledge systems were proposed. Governments were encouraged to increase research on traditional knowledge systems to further understanding and appreciation of that which they have to offer. Another delegate argued for the establishment of 'pluri-technical' teams, bringing together local knowledge-holders and scientists, in order to launch development initiatives with true community involvement from the earliest stages. A proposal presented to establish an international programme on traditional knowledge to address these and other related issues received the general support of the delegates present. Informed consent and equitable profit-sharing were considered to be important fundamental principles for any action in this domain.

Finally, to promote greater understanding and respect for traditional knowledge systems among scientists, it was recognized that disciplines such as the history and philosophy of science have an important role to play. Too few scientists are aware of the contributions of traditional knowledge to science (e.g. drugs from traditional sources; Linnean system of nomenclature founded upon folk classification systems). And too few scientists are alert to the influence of culture, belief/conviction, political ideologies and intellectual fashion on scientific practice. It was proposed that a special commission on traditional knowledge systems be established by the International Union for the History and Philosophy of Science, in order to come to a fuller understanding of, among other things, 'the positivistic and eurocentric focus' that is contemporary science's heritage with respect to traditional knowledge systems.



FORUM III

Towards a new commitment

WORLD CONFERENCE ON SCIENCE

FORUM III

Plenary address

Viktor Orban

Prime Minister, Republic of Hungary

On behalf of the Government, I would like to warmly welcome you all to Budapest. It is such a great pleasure for both Hungary and for the Hungarian Government to be hosting this event. It is also an honour for me personally to be present at such an important meeting. In accordance with diplomatic practices, please allow me now, ladies and gentlemen, to continue my speech in Hungarian.

When I take a look around the room, I have the pleasure of saying that I know some of you personally. I am sure that some of you, or maybe the majority of you, are still surprised to see me on the podium. Many of you may question, is it a good thing for a country to have such a young prime minister? I have thought about this quite a lot and the only answer I can give you relates to the separation pay received by those who served in the army. When those who leave the army receive their separation pay, the years spent in the front line count double. If you use this analogy, I believe that if someone spends 10 years in the jungle of a post-communist country, as I have, then that counts at least triple. If you calculate this, then it is entirely appropriate that you invited me here this afternoon.

I am sincerely delighted to see that in the past days and weeks, ‘Hungary has truly become a shrine of science and education’. First, we hosted the International Forum of Young Scientists, next the Conference of European Education Ministers, and now the first World Conference on Science.

If I am not mistaken about the principal goal and mission of the World Conference on Science, it is to evaluate new opportunities and challenges on the threshold of the new millennium. On behalf of the Hungarian Government, I can assure you that Hungary is ready to shoulder her part in meeting the new challenges of the millennium. All the more so because – and I hope that you will not take me for being partial – the world is full of excellent Hungarian scholars. It is not unusual to find scientists of Hungarian origin behind important achievements and special inventions, although they may be the citizens of other countries. We Hungarians are only just beginning to discover how many of our compatriots are recognized by the global scientific community.

The whole world is now preparing for the millennium – Hungarians especially, since our first Christian king founded Hungary 1 000 years ago. This is why we plan to stage an extensive exhibition to collect all the Hungarian inventions and ideas through which we Hungarians have contributed to world development. Now that the list is prepared, I see that we will need quite a large hall if we really want to show objects ranging from matches, armchairs and computers through to the nuclear reactor.

I think it is worth asking the question why, from such a small country and people, from such a small territory and population, so many Hungarians have contributed to science. I believe that there is an acceptable explanation. Behind these achievements, ladies and gentlemen, you would find the painful reality of the century we are about to leave behind. We have lost so much in the 20th century and those losses were so bitter and poignant that we had to hold on to that which could not be taken from us. As you well know, in this century, Hungary’s territory and population shrank to one-third. You must also know that over the past 50 years the Hungarian economy was practically ruined by a regime very much different from the market economy. But heads and hearts could not and cannot be approached through violence. To members of the Hungarian nation, judgement and thought remained the ultimate refuge. That was the only place where unlimited freedom was available to everyone. And I hope that you agree with me when I say that it is a great feat that numerous Hungarian talents could make use of this freedom in the realm that seems to have been designated for us under those conditions. In short, I can say that perhaps this is what is behind our successes.

Of course it is not a Prime Minister’s job to contemplate the past, but rather to deal with issues that concern the present and the future. It is customary to say about Hungarians that we are pessimistic. Unfortunately, that is still the truth. But I would like to remind you that this was not always the case; in fact there was a time when Hungarians were some of the most optimistic people in Europe. Let me recall the millennium of 1 000 years ago. This is something we may learn from books that you wrote, that at that time the world was full of predictions claiming that 'doomsday' was coming. Important personalities were preparing for the end of the world. At that time, the Emperor Otto III was so pessimistic about the future that he went as far as Ravenna to be closer to the Pope when 'doomsday' arrived. In this atmosphere, the Hungarians led by the first Hungarian king decided to found the Hungarian state. While everyone was preparing for the end of the world, we Hungarians were getting ready for the next millennium.

The reason I am explaining this to you is so you can see that we are not completely hopeless at escaping from this pessimism which has ruled over us in the past.

It is perhaps interesting to say a few words about what preconditions are necessary for us to leave this pessimism behind. The reason I would like to speak about this now is because I believe that pessimism is also an antagonistic opponent of science. I think that, for every serious scientific result (for all upward curving thought), optimism is needed first and foremost. If you like, scientists need to have personal optimism. In this respect, those in state administration and intellectuals perhaps resemble one another. They can only perform well if they believe in the future. Chesterton once said in an essay that optimism is the noble endeavour – and let me stress endeavour – to see more in everything. This optimism is the drive behind all new discoveries as well as the pursuit of research. In recent times, we Hungarians have experienced this truth many times.

He who does not believe that it is worthwhile to excavate a cemetery for 20 years cannot reveal the earliest Hungarian linguistic monument, which actually happened last week in Hungary. He who does not believe that it is worthwhile to quietly contemplate the starry sky every night cannot discover a new planet – because we have a recent example of that, too, in Hungary.

And for a last example, he who does not take a careful look at the contents of a mildewed test tube is highly unlikely ever to recognize how to produce penicillin. Only scientists who are optimistic about the success of their work, who have trust in their future, who are capable of fanatically researching a segment of science can produce sensational achievements, or at least this is the lesson these examples teach us.

Therefore, if I were to translate this into my domain, I would say that the condition necessary for scientific success is to create a country with good spirits, opportunities and hope. Where even air can give strength to people, it will not be difficult to find successful scientists. And we in Hungary, in Parliament, in Government, as well as in the Hungarian Academy of Sciences, are working to make Hungary such a country.

If you will permit me, I will now renounce boasting of our achievements in science in the past year, in attempting to make a list of them. This is likely to have been done for us by others, although I hope Minister Hámori, Chairman of the Conference, will not fail to do it. But I must tell you that we cannot be satisfied with any success until parents in Hungary come to think that it is worthwhile to encourage their children to pursue a career in science. Unfortunately, that moment has not yet arrived. But I very much hope that that moment will come. As you have had the chance to see, Hungary is a country with upward trends, with bright prospects. And what may be even more important, the reason why Hungary is a country with upward trends is that we are not without partners. The whole of Central Europe, or at least its western part, is on an economic and intellectual rise. Analysts predict the brightest prospects for Slovenia, Hungary, Slovakia, the Czech Republic, Poland, from the Adriatic up to the Baltic sea. We see a region of the world where constitutionality is on stable foundations, where governments are stable and the rate of growth of the economy is double that of the European Union. All this justifies our being hopeful and I hope it will also allow Hungarian scientists to increasingly contribute to your common achievement, to the common achievement of the world's community of scientists. I would like to wish you a pleasant stay in Hungary and I would like to ask you to remember fondly Hungary and the Hungarians.

FORUM III

International Forum of Young Scientists

On 23 and 24 June 1999, 150 young scientists (average age 25) from 57 countries met at the International Forum of Young Scientists, a satellite conference of the UNESCO-ICSU World Conference on Science. After two days of discussions the participants adopted the following statement, which they submitted to the World Conference on Science.

I. Summary of major recommendations

The participants in the Forum established the International Forum of Young Scientists as a continuous platform to discuss general issues and challenges to science. They hope that the World Conference on Science will recognize this new body, and request that UNESCO and ICSU involve the Forum in their ongoing programmes.

The participants in the Forum also recommend that:

- scientists increase their responsibility to inform the public openly about research and its wider implications and therefore learn communication skills;
- science education at all levels be strengthened and scientists collaborate with educators;
- education present science in a cross-disciplinary manner;
- ethical aspects be a part of all scientific undertaking and that a special focus on ethics be included in all education programmes;
- scientists take full responsibility for providing help to the scientific communities in less developed countries and urge their governments to support long-term grants for fundamental research to maintain sustainable growth;
- scientists assume increased responsibility for environment and development programmes;
- young scientists participate in decisions made about science.

II. Forum report and detailed recommendations

Introduction

Let us imagine that distinguished scientists gathered in 1899 at a conference in order to discuss the prospects for science in the next century. Optimism would have been high – the belief in the omnipotence of science unshaken, the march towards an always happier world, aided by science and technology, uninhibited. These scientists could not have imagined the discoveries which were soon to follow, which pulled every bit of firm ground from under their feet and which led to the creation of totally new areas of science. They could not have imagined the two terrible world wars in which science played a role and which raised earlier unknown questions of conscience for scientists. They could not have anticipated the unsolvable challenges posed by environmental pollution and overpopulation; nor could they have predicted the hitherto unprecedented presence of science and technology in every nook and cranny of life. Probably only a genius could see the coming developments in aerospace technology, life sciences, information and communication technologies. These few introductory sentences should warn us that, looking at the events in a historical perspective, our ability to foresee trends and developments is very limited and must be treated with great care. What follows are the thoughts of young scientists, who met at the end of the 20th century to reflect about science and its social implications as reflected in the draft *Declaration on Science* and *Science Agenda – Framework for Action* of the World Conference on Science.

1. Science and society

In a democracy people have the right to contribute to the decisions of society. However, to make their decisions, they need information. Science can greatly help society to provide much of this information.

Therefore, the public must be informed openly about research and its wider implications. Science also has to meet and listen to people's needs and each country's priorities. Therefore the scientific community should have the right to discuss research budget distribution with governments.

Education in communication skills will help scientists fulfil their responsibility to provide information to other members of society. However, one should never forget that science is only one voice among those formulating the common will.

Although it is important for a scientist to have a social conscience, the ability of a scientist to increase happiness is limited. A scientist or an engineer can address or solve only problems of a scientific or technological nature, whereas social scientists can propose only specific policies or identify problems which, in many cases, can indeed alleviate the hardships of people. Nevertheless the other sources of human misery are beyond the reach of the traditional domain of science. This is the domain of value systems of a society which only the society as a whole can change. Science is embedded in a social environment and cannot, alone, bring about change. Ultimately, science is not the only form of human knowledge. Traditional forms of knowledge are equally valuable.

The bond between peace efforts and the scientific community should be strengthened. The year 2000, the International Year of Culture of Peace, marks a good opportunity for this new commitment.

2. The relationship between science and education

Developing countries' scientists should encourage governments to pay more attention to wider access to primary and continuing education. A holistic approach to education can bring an early understanding of science and its impact on the environment, whereas an illiterate society can hardly understand the work of scientists.

In institutions of higher education, a deterioration of standards can be observed. University staff are judged almost exclusively on the basis of scientific work. Good teaching is often not rewarded in career terms and the real losers of this process are the students. Educational activities have to be valued more. Institutions should ensure that all members of the academic community engaged in education are provided with appropriate training, resources and support. There is increasing economic pressure on most universities. In many countries, universities are being reorganized along the lines of companies in an attempt to make them more efficient. Although there are a few positive effects of this, the main consequences are that expenditure is cut so that staff numbers are reduced, while the number of students is largely increased. Wider access to higher education, however, should be accompanied by efforts to maintain standards.

3. Science education

More serious efforts are certainly needed to make scientific results marketable and inform the public more adequately. We believe that scientists must accept the essential moral obligation to spend a considerable amount of time as educators and/or collaborate with educators in order to raise the level of scientific and technological literacy, starting with the education of young children in schools.

However, the independence of the educational system and educators must be preserved and appreciated. The entry of new generations into science is highly random and too heavily influenced by subjective factors. Only a few systematic attempts are made to draw the best and most capable young students into scientific research. Research curricula generally do not build expertise in setting even simple research agendas or conducting experiments. Special courses should be established on 'How to select a new research topic', etc. High-school student research training programmes should be more widely developed to utilize this highly influential life period to build a long-lasting and deep commitment to scientific research. Pre-college students should be encouraged to participate in international science fairs and other such programmes. This will enable them to engage in independent research and develop necessary communication skills. The established scientific community should assume mentorship roles and regard pre-college students as a growing population of curious, young scientists.

4. Deterioration of standards in science

The constant fight for grants and the administration of small, fragmented grants cause scientists to spend more time on paperwork and less on truely scientific work. There is too much competition in certain branches of science today. The well-known saying 'publish or perish' expresses the pressure to produce a large number of partly irrelevant publications instead of taking time to think more profoundly.

In addition, the exponential rise in the number of publications makes it very difficult for potential readers to filter useful information. Evaluation based on the number of publications has a further undesirable side-effect: it hampers the free flow of information because of the fear of priority debates.

Another problem is the increasing compartmentalization of thought. With the astonishing degree of specialization, most scientists become experts in a very narrow field and are often unable to think in a broader context. Thinking about the whole can lead to deeper insights. The aforementioned pressures, however, make such an approach difficult. We hope that in the future the importance of interdisciplinary research will increase and the holistic approach to problem-solving will gain ground against purely analytical thinking.

5. Ethical considerations

Science bears a general responsibility for the well-being of humanity. Every scientist must have a constant awareness of the possible consequences of her/his research. A full and open dialogue involving various sectors of society is necessary to consider the consequences of experiments like human cloning and genetic engineering before their initiation. More forceful legal and moral safeguards should be worked out to prevent unethical practice and misuse of science for the development of weapons of mass destruction, and for experiments which disregard the dignity of human persons or animals. A special education on ethics should be included in all education curricula. Scientific information has to be handed over to the public and should not be held back for economic or political reasons. Science is embedded in society so that scientific ethics are inseparable from the ethics of the society as a whole.

We expect and encourage the global scientific community to try to find a consensus on the self-regulation of science. In agreement with a former version of the draft *Declaration on Science* of the World Conference on Science, we strongly support the establishment of a scientific Hippocratic oath.

6. Science and equal opportunities

We recognize and appreciate the growing demand to end the discrimination against women. It is also necessary for different ethnic, national and other minorities, who are victims of discrimination, to have equal chances and broadened opportunities in education and science. We encourage education policy-makers to do their best to ensure social justice and encourage women to join scientific research.

However, we want to protect the autonomy of internal scientific standards and the disciplinary structure of sciences against direct political and social influence, regardless of the good and noble intentions of policy-makers.

7. Science and development

Science can help to reduce the gap between the developed and developing countries by ensuring that scientific information flows freely and to all parts of the world. The Internet plays an important role in this, although more attention needs to be paid to ensuring that its reach is both geographically and linguistically extended. Financial support for science in developing countries needs to be enhanced and more cooperation encouraged. Scientists have an important role to play in protecting the environment and scientific projects should both respect the requirements and contribute to sustainable development. Scientists should support research on appropriate technologies. Traditional knowledge should not be rejected by scientific knowledge, particularly in the area of national resource management. Care should be taken to protect the intellectual property rights of people providing indigenous forms of knowledge.

While we fully support the free circulation of scientists we recognize that this makes the so-called brain drain inevitable. Brain drain has often been referred to as a negative phenomenon in which scientific talents would be permanently siphoned away from poorer to richer countries. The positive effects need, however, also to be emphasized: many persons from developing countries educated in the West return to their native land and hence raise the level of local education there; or, if they remain abroad, often represent the interests and needs of their native country, keep their contacts and thus help improve the situation in the native country itself. Being aware of these positive effects, we stress that, to encourage a greater repatriation of these scientists, a special home-coming grant system is needed.

8. Career prospects for young scientists

In market-based economies, relatively young people can reach high positions of great responsibility. In the hierarchic world of science, however, a person under the age of 40 rarely gets into a leading position. This endangers the preservation of the freedom of research for young scientists. Young people with fresh ideas should be included more in the decision-making processes and new, less rigid structures should be found. Science as a profession is often financially unattractive and there is very rarely satisfactory job security.

Consequently, young talented people rarely stay in science once they find a more attractive job. This is also a crucial factor affecting the quality of science, when science is unable to hold on to its brightest talents.

9. Fundamental, applied and military research

A significant portion of science is funded today from private sources, which are, understandably, more interested in direct applications than long-term basic research. It is very important, however, that governments keep supporting longer term (i.e. longer than an election cycle) fundamental research and install a legal framework which promotes the mobilization of private finding for this purpose. We believe that such long-term projects can contribute to sustainable growth.

Although military R&D serves certain (real, imagined or artificially created) needs of society, we believe that there is a need for companies or government institutions to help transfer these results to the civil sphere.

III. Mechanism for implementing the recommendations of the Forum

Students and scientists at the beginning of their careers have a fresh and unburdened attitude towards the ethical and moral issues facing science. Therefore we, the participants of the International Forum of Young Scientists, established the International Forum of Young Scientists as a continuous platform to discuss general issues and challenges facing science. The Forum will maintain an Internet site where ideas about the development and contexts of science could be posted and discussed. The Forum will analyse the possibility of establishing a journal for young scientists, initially as an Internet site. The Forum will have regular meetings in various places around the world. We ask the Secretariat of the Budapest International Forum of Young Scientists to be the Secretariat of the new body, which task they can pass to the organizers of the next meeting. The Secretariat would be responsible for propagating the relevant proposals of the Forum to relevant decision-making bodies and to the general public. We ask the World Conference on Science to recognize this Forum and request that UNESCO and ICSU involve the Forum in their ongoing programmes.

FORUM III

International NGO Consultation

Recommendations

The non-governmental organizations (NGOs) represented at the International NGO Consultation held within the framework of the World Conference on Science, Budapest, 27 and 28 June 1999:

- endorse in principle both the proposed *Declaration* and *Framework for Action*;
- believe that the following recommendations presented by them will significantly contribute to the improvement of both documents;
- offer their expertise in further planning and implementing the new commitment to science in the 21st century.

General observations

Some of the global issues have not been given sufficient priority in the working documents of the Conference. They should be mentioned in the preambles as key issues to be addressed:

- quality of air and increasing levels of greenhouse gases, specifically carbon dioxide;
- availability of fresh water;
- availability of food.

Health-related sciences are of the greatest importance as a response to human needs. A balanced development and application of these sciences, to be inclusive of all groups, are key factors in health improvement the world over. Emphasis should be placed on prevention and health promotion, including mental health, with particular reference to existing needs. Because the burden of disease is greatest in those countries which currently receive the least contribution from science towards prevention and cure, the community of scientists should strive to focus efforts on the health needs of the poorest countries. Governments and international organizations should increasingly rely on the experience in this field of the relevant international scientific organizations and other NGOs.

The issues covered, as reflected in the documents, need to be more gender-inclusive and sensitive to issues of other groups.

Science has lost its glamour and attractiveness for children, both girls and boys, which is contributing to the decline of interest in scientific and engineering endeavours. More emphasis should be placed on science education for girls and boys.

Young scientists, both women and men, are the future of science. Development of their potential and nurturing of their talents should be the responsibility of the professional scientific community.

Development, dissemination and acquisition of scientific knowledge require a systematic effort in order to overcome gender, social, cultural and ethnic inequalities.

Electronic means offer the best potential for promoting communication and access to up-to-date scientific information. The growing gap between the haves and the have-nots in use of electronic communication poses a challenge and creates opportunities for developed countries to work in partnership with less-developed ones.

FORUM III

Towards a new commitment

Review

Forum III provided the occasion for a major international dialogue on the future of science. Distinguished representatives from 155 countries, including 80 ministers of science and technology, research and education or their equivalents and 126 intergovernmental and non-governmental organizations, were invited to take the floor to share their views and make proposals for engaging in a new partnership in science.

The Forum took the form of a single plenary debate spread over five sessions. In their introductions, the Chairman and Secretary-General of the World Conference on Science each urged speakers to focus on the commitment the scientific community should make to society in future and on the commitment science should expect from governments, policy-makers, international organizations, the private sector and society at large in return. In other words, speakers were asked to define their vision of the new social contract for science in the 21st century.

The debate was nurtured by the outcome of the two preceding Forums, summarized by the rapporteurs before the debate got under way, and by the two principal documents the Conference was about to examine, namely the *Declaration on Science and the Use of Scientific Knowledge* and the *Science Agenda – Framework for Action*. In his introduction, the Secretary-General also drew the participants' attention to the recommendations of the associated meetings held prior to the Conference.

A total of 129 speakers from 103 countries and 26 international organizations took the floor during the course of the debate. Although the Conference did not require the preparation of a formal report, since Forum III was conceived as a direct dialogue between participants, the Secretariat has considered it useful to present salient points of the discussion below.

Concerns and proposals

The speakers analysed the current situation and/or made concrete action-oriented proposals and plans for follow-up to the World Conference on Science. The analytical part of the presentations addressed the mission of science in the 21st century, the challenges science is to face and the services it is to provide, as well as the content of the principal Conference documents.

When making their analysis, many speakers highlighted the need to give priority to:

- the sharing of knowledge and assistance for capacity-building in developing countries;
- the promotion of science education;
- strengthening the role of women in science;
- ethical issues arising from progress in science;
- the preservation of biodiversity and the environment.

Many spoke of the need for priority-setting within science and technology policy-making, South-South cooperation, the interface between natural and social sciences, the preservation of indigenous and traditional knowledge, and the popularization of science. Other speakers drew the audience's attention to the funding of science, brain drain and the relationship between science, religion and the spiritual quest. While it would not be expedient here to recapitulate all the issues touched upon, it is noteworthy that the analysis made by the speakers led to a broad understanding on where science should be heading in the 21st century. These conclusions were incorporated into the two principal documents and endorsed by the Conference before participants dispersed.

Most presentations to Forum III took the form of a statement on follow-up to the Conference. Over 90 proposals were made by representatives of national delegations and international organizations. These proposals referred to:

- commitments and/or plans at the national level;
- programmes or projects to be launched or developed;
- centres of excellence or international institutes to be set up or strengthened;
- regional and international networks;
- regional and international initiatives to be undertaken;
- conferences to be convened;
- actions to be taken with regard to international normative documents and agreements;
- the steering of Conference follow-up.

One of the primary goals of the World Conference on Science was to trigger development at the national level. It is the countries themselves which are supposed to act upon, and benefit from, an enhanced commitment to science and international cooperation. Therefore, action at the national level constitutes the core of follow-up. During the course of Forum III some 20 countries made a number of their commitments and plans known. To cite but a few:

- an increase in funding for science and technology (seven countries);
- implementation of a new plan for research, development and innovation for 2000-03;
- development of a national innovation system with the full participation of indigenous people and women in the scientific and technological enterprise, as well as preservation of the country's wealth of biological diversity;
- introduction of a new policy in science and technology, to be identified with the assistance of the United Nations Development programme (UNDP) and UNESCO;
- a radical improvement in national education and science and technology within one country's Vision 2010 Programme;
- a strategic initiative to prepare the young for the scientific disciplines and the professions of the future.

Other proposals embraced a wide range of actions at the international or regional levels. These proposals referred in particular to:

- the International Auger Project on Cosmic Radiation;
- a programme to inform scientists in developing countries about the use of intellectual property rights;
- the establishment of a World Water Institute;
- reinforcement of the instruments for regional and international cooperation;
- promotion of UNESCO's global Molecular and Cell Biology Network;
- the development of an early-warning system to combat desertification.

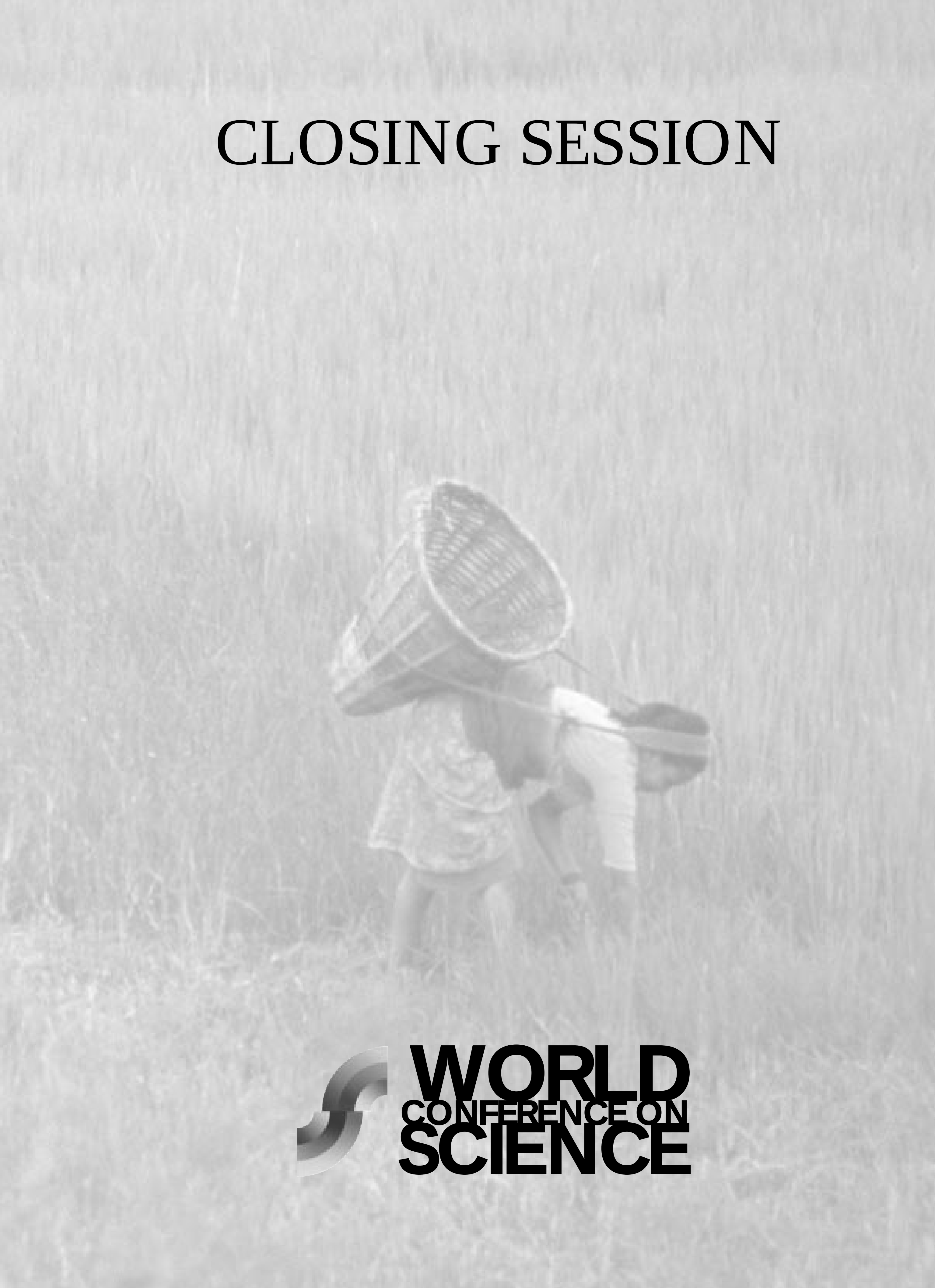
A Conference of African Ministers for Science and Technology in 2000 was announced and a reexamination of intellectual property rights proposed. With regard to the steering of Conference follow-up, one speaker suggested that a committee be established to launch follow-up action and evaluate the returns. In addition to representatives of UNESCO and ICSU, such a committee would include representatives of regions and bilateral and multilateral partners.

Forum III offered national delegations and international organizations the opportunity to reaffirm, in public, their commitment to attaining the goals proclaimed in the *Declaration* and to following the recommendations set out in the *Science Agenda*. Many speakers declared that they would walk away from Budapest armed with fresh determination. They emphasized the value of the *Agenda* as a framework for action and encouraged other partners to adhere to it. Some pointed out that the United Nations system and other stakeholders should use the *Science Agenda*, or relevant parts of it, when planning and implementing concrete measures and activities that embrace science or its applications. They stated that, in this way, a truly multilateral and multifaceted programme of action would be developed.

The present recapitulation is far from exhaustive, its purpose being merely to illustrate the type, scope and variety of the proposals made. The various presentations provide a practical basis for action by interested partners and give guidance to the nascent steering body for follow-up to the Conference.

The Statements made to Forum III by the International Forum of Young Scientists and by the NGO Consultation, two meetings which formed an integral part of the Conference programme, are reproduced in the present Proceedings, as well as the address of Mr Viktor Orban, Prime Minister of Hungary. Those wishing to learn of the contents of individual presentations to Forum III may like to consult the Conference website (www.unesco.org/science/wcs) or contact the UNESCO Secretariat.

CLOSING SESSION



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Closing address

Werner Arber
President, ICSU

We arrive at the end of six days of intensive work. This has brought us a number of very interesting moments where experience was acquired and where we also made experiments. As scientists, we of course depend very much on experiments. During this week we experimented with close interactions between scientists, policy-makers and other representatives of society. I consider this kind of interaction an excellent strategy to proceed with in planning for future developments.

Two days ago a request reached me to provide, with a narrow deadline, a written manuscript of my present speech. In general, I am collaborative, but after some reflection I felt that for symbolic reasons I should not follow that request and I would like to explain to you why: it belongs to the scientific method that you design an experiment, you carry it out, you collect data and at the very end you sit down and reflect, take conclusions and if you reach good conclusions you are going to write a publication which is made available to the scientific community. It does not follow the rules of honesty if a publication is written before the data are collected, nor before reflections on conclusions are made, and therefore I felt that I should not provide the manuscript ahead of time and I apologise to the interpreters. In fact the manuscript, I think, should also have been distributed to the press, which means that it would have already been a publication before the end of the Conference. I read from the *Declaration*, now adopted, that we ask all scientists to 'follow basic ethical principles and responsibility' and I hope with that decision of mine I hold to that rule.

I will just make a quick conclusion after the adoption of the *Declaration* and *Framework for Action*. I am very pleased to see that the assembly, composed of scientists, policy-makers and other representatives of society, has come to an agreement, that it is time to recognize that science, its acquired knowledge and its applications have cultural values and that they are essential for the further development of our civilization. What kind of impact do we see in the scientific enterprise? There are two large groups formed by, on the one hand, practical applications, technology of all kinds and medical applications, food production and so on and so forth, which satisfy human needs and by this also improve prosperity. On the other hand, there is the second group of impacts formed by philosophical applications of knowledge. Bringing the world-view up to date, they can foster an increased consciousness of a human mission in a complex world. I think that many of our scientific insights can help human beings to find that way, to find the sense of their personal lives and of their life in the community. An updated world-view represents a solid basis both for formulating and implementing human rights and human duties.

This leads me to a few words on the social contract. Social contract means mutual help, respect for each other and a call to implement the statement 'Science for Society and Society for Science'; in this, the contract is mutual, each partner gives and is also interested in accepting. In my experience, the awareness of such a contract has up to now not been so great in the scientific community, nor in society, and I do hope that the World Conference on Science and its amplifications, not least by the press, can help to foster awareness of the existence of such a contract and of its meanings.

Both in society and among scientists, how should we further proceed? It is the *Framework for Action* which can provide us with guidance. From the point of view of the scientific community, i.e. ICSU, I do not think that we should talk of a revolution if we start on a new social contract. Rather, I would like to suggest that we follow a widely experienced and improved rule of nature, which is to pave the way to the future by a smooth and steady evolution. I am an evolutionary biologist who tries to understand better the process of evolution. Already in the early times of Darwinism, it had been explained that, among other factors, two central principles were very important for biological evolution. First, that there occurs some genetic variation in populations – scientists call it mutation. The second aspect is natural selection, which is exerted by the context in which the organisms live. In the long term, those organisms and genetic variants which are best adapted to the encountered environments are the winners in natural selection, which is thus a regulative process driven by the availability of genetic variants. So, both are important, genetic variation as well as natural selection.

Let us now make a comparison with our future task. The outcome of the Conference, the *Declaration* and the

Framework for Action, can be compared with natural selection: they set the stage for decisions on what things should be favoured and what things should not be given priority. The occurrence of mutation or variation will drive the process. We are asked as scientists to develop good ideas; they have not all by a long way been formulated yet. We should take this as a stimulus to think about what to do in order to reach new goals. For example, by which process could we best initiate new programmes for collaborative efforts to benefit from scientific progress at a global level. ICSU very much looks forward to receiving ideas and we plan to discuss them and turn them into action. If they are consistent with the *Framework for Action*, I am pretty sure that we can expect, as with natural selection, that appropriate actions and programmes will give some beneficial results in due time.

ICSU commits itself, as proposed, to submitting the results of this Conference to its next General Assembly, to be held in September 1999 in Cairo, Egypt, and we also take that event as the initiation of the follow-up process. In the meantime, we have some time to reflect then make good proposals to the General Assembly. I am very pleased to see in the final documents of the Conference that ICSU and UNESCO have been accepted as equal partners for future activities and we are grateful to UNESCO to have proposed, and to the assembly to have been willing to accept, that collaboration at a very high level. We believe that, in having a mission and a programme of action which we can carry out together with UNESCO, we can provide a very important cultural contribution, which is at the heart of UNESCO's aims. Certainly, we will seek collaboration with other groups and many are already present here and have made very important contributions, so we will not forget all those organizations worldwide which are helping to reach the goals set in this Conference. We need to move towards a responsible, peaceful and sustainable coexistence between all members of human society. This is also important in order to safeguard the entire living world as well as the inanimate world. We human beings are part of one global system in the process of development, of evolution and representing matter and life in its rich diversity. It is the intellectual capacity of human beings which paves the way to our cultural evolution. We should mobilize human intelligence to let this evolution thrive in a responsible way in a society living in peace with a well-preserved biosphere embedded in its natural substrate on that planet – Earth.

I would not like to leave the podium without offering my sincere thanks to all those present or even absent today who have helped in the preparation of the Conference, during the Conference and who are fully committed to future follow-up. The warmest thanks to our Hungarian hosts have already been expressed many times, but I consider it appropriate to repeat them now. I am convinced that the World Conference on Science will be seen by historians in retrospect as a highlight in the very long tradition of care for science in Hungary.

Closing address

Federico Mayor
Director-General, UNESCO

As we come to the close of the World Conference on Science, I would like once again to express my deep gratitude to our hosts for making our stay here in Budapest such a memorable one and I also want to say how very grateful I am to all the participants. You have deployed so much energy over the last six days and contributed to so many important debates that our final documents can truly be said to result from an active and – I may add – a highly interactive process, especially in the case of the excellent role played by the rapporteurs, the drafting group and the chairs of the thematic meetings. So I warmly thank the government officials, the scientists, the engineers and the educators, the employers, the representatives of private enterprise, NGOs and the media for this remarkable input, which is the first great achievement of the Conference.

I have been greatly encouraged by what I have seen this week. The outstanding feature of this Conference has been the constructive way everyone has worked together, all actors on the same stage. Basic science researchers have been getting to grips with issues which they may not always have considered as aspects of their work. I must say how much I have admired their willingness to respond to this role of scientist as global citizen. There have also been government ministers and other officials, listening to the natural scientists, to the social scientists, to the non-governmental organizations (NGOs), and I thank them too for entering into this very open dialogue. Each and every person here has fully played his or her part. I am especially grateful because the relationship between science and society that we are seeking for the start of a fresh century makes learners of us all. In order to establish a new way of doing science, we have to learn to take the dialogue about science, policy, social needs and ethics to a new level and that is why I am so glad we have launched UNESCO's first *World Social Science Report* here in Budapest.

We have to learn to practise democracy at a new level: a level where each party to the science-society relationship is a respected partner, where there is constant interaction between the natural and social sciences, where science communication becomes a process of two-way exchange between science and society, between science and politics. Science popularization has to enrich debate and feed a growing exchange on the issues. Because, if the 21st century is to be marked by a closer relationship and a new role for science, believe me there will be debate! There must be debate – so intense, so creative, so ethically rigorous, so intellectually challenging that it comes to be seen as a social, political and, yes, a scientific Renaissance – one in which universities, academies, research councils and institutes, parliaments, the media and associations for the advancement of science mobilize to link everyone, within and between countries, to the knowledge base of humanity.

Much has been said about public disenchantment with science. What saddens me most is the disenchantment of many young people. This new departure must get young people lining up to enrol in science classes, viewing science as an outlet for their idealism, as the vehicle for making ours a better world: one where scientific knowledge is applied in a timely way, to redress but also to anticipate and prevent the problems which keep so many people in poverty, with no choice but to migrate to the shanty towns or to emigrate. A better world, where the best talents – the treasure within – do not fly away and where we apply knowledge to narrow and bridge the gap between the extremes of prosperity and exclusion, this unresolved paradox of our times; a world where science ensures the sustainability of development within a democratic context – that is the best way to build justice and security, to facilitate the transition from a culture of force and confrontation to a culture of tolerance and dialogue, a culture of peace.

And for this to happen on a massive scale, we need a new commitment at all levels. First and foremost, the outcome of this Conference must impact directly on national policies. Here I turn to all the government officials present in this room to emphasize once again how much depends on you. When you go back to your governments and parliaments, please ensure that the documents adopted here are debated in your national assemblies, in cabinet meetings, in the parliamentary select committees, in science policy groups. I know there is no point in dreaming that I will hear next week that all your governments have agreed to increase overnight the percentage of research spending to the levels we are calling for. But I do dream that you will put science on the political agenda and keep it there, that it will become the norm to devote a day a year to parliamentary debate on research policy.

This is a crucial time for science. What does it mean when we say we live in a knowledge society? When we say information and knowledge are the main resource and the real currency of our age? It means that, for the first time ever, the key resource of humanity is not finite. We will never have to wage wars over diminishing supplies of knowledge! Of course, knowledge is power and the temptation to control such a powerful resource will be greater than ever. But equally, there are powerful tools to resist knowledge monopolies, knowledge deprivation, knowledge discrimination. Knowledge lends itself to sharing, to dissemination, to incremental growth, and information and communication technology now offers the means to share, disseminate and expand knowledge on a totally unprecedented scale.

It is this process of sharing and developing the knowledge base to which we must now turn our efforts. Our professional activities are more than just jobs – underlying them is a mission: to improve the lives of human beings. Capacity-building in the developing world must put emphasis on basic science more than technology transfer. Only this can put each country in charge of its applications of science and technology. How can we achieve this? As Michael Southwick said here, speaking for the United States, the answer is: all together, through dialogue and cooperation. He is so right! Even the biggest country cannot go it alone and even the smallest country cannot expect outside assistance without first making its own efforts – both in terms of budget and of policy.

ICSU and UNESCO will play their role in implementing the resolutions made here and ensuring the relevance of follow-up initiatives. Thanks to Internet and e-mail, the outreach of our follow-up will extend as far as the widest network. We have a *Declaration* that unites us in our general aims and a *Framework for Action* that allows each country, each region, each network of institutions to select its own most urgent priorities. UNESCO and ICSU will of course not be alone in the task of international follow-up and I already welcome all those from NGOs, from business and from the Youth Forum who will join our working group. And, of course, all the participants here will have a role to play in their own workplace and community. We must all implement follow-up initiatives if we are to reach the scale of capacity-building needed, if we are to forge the kind of links between science and decision-making that allow for timely scientific advice to be heard and to be used. Some may think these expectations are too high. Some may wonder whether the demands of the role of scientist as global citizen will not be too great. But I believe that if we do not commit ourselves to a fundamentally new way of doing science, the costs will be far higher in terms of lost opportunities, in terms of the uncontrolled transformation and fragmentation of scientific activity under the weight of market pressures and, above all, in terms of the dangerous acceleration and accumulation of critical problems for society and our planet that are crying out for scientific solutions. If any one thing should urge us on, it is the risk of irreversibility that now hangs over some of the most crucial processes of change that we are witnessing today.

When I opened this Conference, I said that the Danube does not separate Buda and Pest. It joins them. It seemed a fitting symbol for our undertaking. And we have indeed been joined, not separated, this week, by our different backgrounds and approaches, by the diversity of our areas of knowledge and of concern. As His Excellency, the President of Hungary, said in his opening speech: ‘There is only one science, only one planet Earth and only one humankind’. This is a truth that has come home to us here in Budapest. We have it in our power to contribute to the well-being and the human dignity of people who will never hear of our Conference, but whose lives we can improve. And now, as we split up and go our separate ways, we take with us a shared determination. Although we each leave on our own journey, we have done our mapping together and, even after we separate, we remain joined by a shared – by a new – commitment.

Closing address

József Hámori
Minister of National Cultural Heritage, Republic of Hungary

It is my honour and duty to deliver the closing remarks at the World Conference on Science. It is quite a privilege and, at the same time, a challenge.

We have just heard a short overview and analysis of the Conference by President Arber and Director-General Mayor. Both as the Chairman of the Conference and as a Hungarian, I can only join them in congratulating you for what you have accomplished here in Budapest.

What I would like to add and what I believe to be extremely important is this: from the very beginning, the World Conference on Science has been thought of as a process. The one-week meeting that we have had in Budapest has been a kind of assembling of a 'launching pad' for new thoughts, new approaches and common responsibility.

The Conference is coming to an end in a few minutes, but our joint work will continue and I believe it will go on in an environment of better understanding of the challenges humankind is facing and the ways science can contribute to meeting those challenges.

Just think of it! How many people's energy and creativity, and how many working hours have been put in to make this huge project a reality: hundreds of preparatory meetings held, thousands of pages written, millions of kilometres (or if you wish miles) travelled, billions of bits of information exchanged through telephones, faxes, e-mails.

The number of people attending the Conference was about 2 000. The number of people involved in the preparation and engaged in the intellectual fora of this meeting is probably in the range of several dozens of thousands. And the number of people whose life will be in one way or another influenced by the outcome of the Conference is in the range of billions.

Talking just about the Budapest Conference: we, the participants, have done a good job, I believe. There were some 2 000 people in this room making their contribution to the Conference. While thanking you for your hard work and responsible attitude, I would also like to thank all those people who, by working behind the scenes, have kept the wheels turning and run this Conference smoothly. I would like to thank the hostesses, the local organizers, the staff of UNESCO and ICSU for putting this all together and keeping it running. Last but not least, a special word of thanks should go to the interpreters who have made our communication not just possible but smooth and enjoyable.

I would like to thank the press, both international and local, for their hard work and for spreading the word about the World Conference on Science to the general public worldwide.

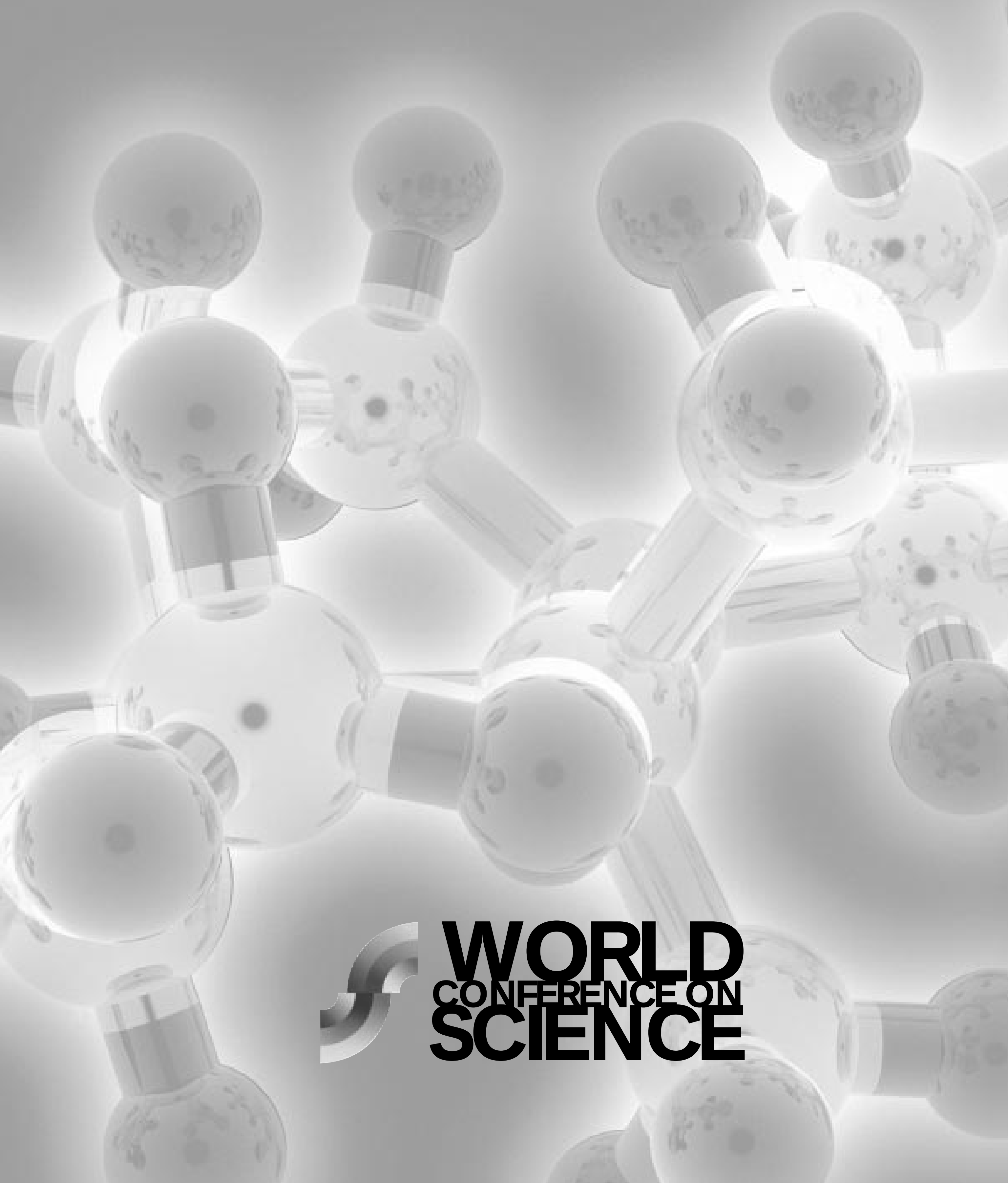
To finish, let me compile a partial list of the most frequently used words at the Conference: science, society, responsibility, humankind, unique, historic, diversity and unity.

I hope the World Conference on Science in Budapest, and every one of you returning home, will carry the message of unity, common responsibility and joint action for the benefit of all of us and humankind as a whole.

We are coming to the end of this century and soon entering a new millennium. I hope that the next century will be the century of peace and science.

I declare the World Conference on Science ended.

CONFERENCE DOCUMENTS



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Declaration on Science and the Use of Scientific Knowledge

Preamble

1. We all live on the same planet and are part of the biosphere. We have come to recognize that we are in a situation of increasing interdependence, and that our future is intrinsically linked to the preservation of the global life-support systems and to the survival of all forms of life. The nations and the scientists of the world are called upon to acknowledge the urgency of using knowledge from all fields of science in a responsible manner to address human needs and aspirations without misusing this knowledge. We seek active collaboration across all the fields of scientific endeavour, that is the natural sciences such as the physical, earth and biological sciences, the biomedical and engineering sciences, and the social and human sciences. While the *Framework for Action* emphasizes the promise and the dynamism of the natural sciences but also their potential adverse effects, and the need to understand their impact on and relations with society, the commitment to science, as well as the challenges and the responsibilities set out in this *Declaration*, pertain to all fields of the sciences. All cultures can contribute scientific knowledge of universal value. The sciences should be at the service of humanity as a whole, and should contribute to providing everyone with a deeper understanding of nature and society, a better quality of life and a sustainable and healthy environment for present and future generations.

2. Scientific knowledge has led to remarkable innovations that have been of great benefit to humankind. Life expectancy has increased strikingly, and cures have been discovered for many diseases. Agricultural output has risen significantly in many parts of the world to meet growing population needs. Technological developments and the use of new energy sources have created the opportunity to free humankind from arduous labour. They have also enabled the generation of an expanding and complex range of industrial products and processes. Technologies based on new methods of communication, information handling and computation have brought unprecedented opportunities and challenges for the scientific endeavour as well as for society at large. Steadily improving scientific knowledge on the origin, functions and evolution of the universe and of life provides humankind with conceptual and practical approaches that profoundly influence its conduct and prospects.

3. In addition to their demonstrable benefits the applications of scientific advances and the development and expansion of human activity have also led to environmental degradation and technological disasters, and have contributed to social imbalance or exclusion. As one example, scientific progress has made it possible to manufacture sophisticated weapons, including conventional weapons and weapons of mass destruction. There is now an opportunity to call for a reduction in the resources allocated to the development and manufacture of new weapons and to encourage the conversion, at least partially, of military production and research facilities to civilian use. The United Nations General Assembly has proclaimed the year 2000 as International Year for the Culture of Peace and the year 2001 as United Nations Year of Dialogue among Civilizations as steps towards a lasting peace; the scientific community, together with other sectors of society, can and should play an essential role in this process.

4. Today, while unprecedented advances in the sciences are foreseen, there is a need for a vigorous and informed democratic debate on the production and use of scientific knowledge. The scientific community and decision-makers should seek the strengthening of public trust and support for science through such a debate. Greater interdisciplinary efforts, involving both natural and social sciences, are a prerequisite for dealing with ethical, social, cultural, environmental, gender, economic and health issues. Enhancing the role of science for a more equitable, prosperous and sustainable world requires the long-term commitment of all stakeholders, public and private, through greater investment, the appropriate review of investment priorities, and the sharing of scientific knowledge.

5. Most of the benefits of science are unevenly distributed, as a result of structural asymmetries among countries, regions and social groups, and between the sexes. As scientific knowledge has become a crucial factor in the production of wealth, so its distribution has become more inequitable. What distinguishes the poor (be it people or countries) from the rich is not only that they have fewer assets, but also that they are largely excluded from the creation and the benefits of scientific knowledge.

6. We, participants in the World Conference on Science for the Twenty-first Century: A New Commitment, assembled in Budapest, Hungary, from 26 June to 1 July 1999 under the aegis of the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the International Council for Science (ICSU):

Considering:

7. where the natural sciences stand today and where they are heading, what their social impact has been and what society expects from them,

8. that in the twenty-first century science must become a shared asset benefiting all peoples on a basis of solidarity, that science is a powerful resource for understanding natural and social phenomena, and that its role promises to be even greater in the future as the growing complexity of the relationship between society and the environment is better understood,

9. the ever-increasing need for scientific knowledge in public and private decision-making, including notably the influential role to be played by science in the formulation of policy and regulatory decisions,

10. that access to scientific knowledge for peaceful purposes from a very early age is part of the right to education belonging to all men and women, and that science education is essential for human development, for creating endogenous scientific capacity and for having active and informed citizens,

11. that scientific research and its applications may yield significant returns towards economic growth and sustainable human development, including poverty alleviation, and that the future of humankind will become more dependent on the equitable production, distribution and use of knowledge than ever before,

12. that scientific research is a major driving force in the field of health and social care and that greater use of scientific knowledge would considerably improve human health,

13. the current process of globalization and the strategic role of scientific and technological knowledge within it,

14. the urgent need to reduce the gap between the developing and developed countries by improving scientific capacity and infrastructure in developing countries,

15. that the information and communication revolution offers new and more effective means of exchanging scientific knowledge and advancing education and research,

16. the importance for scientific research and education of full and open access to information and data belonging to the public domain,

17. the role played by the social sciences in the analysis of social transformations related to scientific and technological developments and the search for solutions to the problems generated in the process,

18. the recommendations of major conferences convened by the organizations of the United Nations system and others, and of the meetings associated with the World Conference on Science,

19. that scientific research and the use of scientific knowledge should respect human rights and the dignity of human beings, in accordance with the *Universal Declaration of Human Rights* and in the light of the *Universal Declaration on the Human Genome and Human Rights*,

20. that some applications of science can be detrimental to individuals and society, the environment and human health, possibly even threatening the continuing existence of the human species, and that the contribution of science is indispensable to the cause of peace and development, and to global safety and security,

21. that scientists with other major actors have a special responsibility for seeking to avert applications of science which are ethically wrong or have an adverse impact,

22. the need to practise and apply the sciences in line with appropriate ethical requirements developed on the basis of an enhanced public debate,

23. that the pursuit of science and the use of scientific knowledge should respect and maintain life in all its diversity, as well as the life-support systems of our planet,

24. that there is a historical imbalance in the participation of men and women in all science-related activities,

25. that there are barriers which have precluded the full participation of other groups, of both sexes, including disabled people, indigenous peoples and ethnic minorities, hereafter referred to as disadvantaged groups,

26. that traditional and local knowledge systems, as dynamic expressions of perceiving and understanding the world, can make, and historically have made, a valuable contribution to science and technology, and that there is a need to preserve, protect, research and promote this cultural heritage and empirical knowledge,

27. that a new relationship between science and society is necessary to cope with such pressing global problems as poverty, environmental degradation, inadequate public health, and food and water security, in particular those associated with population growth,

28. the need for a strong commitment to science on the part of governments, civil society and the productive sector, as well as an equally strong commitment of scientists to the well-being of society,

Proclaim the following:

1. Science for knowledge; knowledge for progress

29. The inherent function of the scientific endeavour is to carry out a comprehensive and thorough inquiry into nature and society, leading to new knowledge. This new knowledge provides educational, cultural and intellectual enrichment and leads to technological advances and economic benefits. Promoting fundamental and problem-oriented research is essential for achieving endogenous development and progress.

30. Governments, through national science policies and in acting as catalysts to facilitate interaction and communication between stakeholders, should give recognition to the key role of scientific research in the acquisition of knowledge, in the training of scientists and in the education of the public. Scientific research funded by the private sector has become a crucial factor for socio-economic development, but this cannot exclude the need for publicly funded research. Both sectors should work in close collaboration and in a complementary manner in the financing of scientific research for long-term goals.

2. Science for peace

31. The essence of scientific thinking is the ability to examine problems from different perspectives and seek explanations of natural and social phenomena, constantly submitted to critical analysis. Science thus relies on critical and free thinking, which is essential in a democratic world. The scientific community, sharing a long-standing tradition that transcends nations, religions and ethnicity, should promote, as stated in the Constitution of UNESCO, the ‘intellectual and moral solidarity of mankind’, which is the basis of a culture of peace. Worldwide cooperation among scientists makes a valuable and constructive contribution to global security and to the development of peaceful interactions between different nations, societies and cultures, and could give encouragement to further steps in disarmament, including nuclear disarmament.

32. Governments and society at large should be aware of the need to use natural and social sciences and technology as tools to address the root causes and impacts of conflict. Investment in scientific research which addresses them should be increased.

3. Science for development

33. Today, more than ever, science and its applications are indispensable for development. All levels of government and the private sector should provide enhanced support for building up an adequate and evenly distributed scientific and technological capacity through appropriate education and research programmes as an indispensable foundation for economic, social, cultural and environmentally sound development. This is particularly urgent for developing countries. Technological development requires a solid scientific basis and needs to be resolutely directed towards safe and clean production processes, greater efficiency in resource use and more environmentally friendly products. Science and technology should also be resolutely directed towards prospects for better employment, improving competitiveness and social justice. Investment in science and technology aimed both at these objectives and at a better understanding and safeguarding of the planet’s natural resource base, biodiversity and life-support systems must be increased. The objective should be a move towards sustainable development strategies through the integration of economic, social, cultural and environmental dimensions.

34. Science education, in the broad sense, without discrimination and encompassing all levels and modalities, is a fundamental prerequisite for democracy and for ensuring sustainable development. In recent years, worldwide measures have been undertaken to promote basic education for all. It is essential that the fundamental role played by women in the application of scientific development to food production and health care be fully recognized, and efforts made to strengthen their understanding of scientific advances in these areas. It is on this platform that science education, communication and popularization need to be built. Special attention still needs to be given to marginalized groups. It is more than ever necessary to develop and expand science literacy in all cultures and all sectors of society as well as reasoning ability and skills and an appreciation of ethical values, so as to improve public participation in decision-making related to the application of new knowledge. Progress in science makes the role of universities particularly important in the promotion and modernization of science teaching and its coordination at all levels of education. In all countries, and in particular the developing countries, there is a need to strengthen scientific research in higher education, including postgraduate programmes, taking into account national priorities.

35. The building of scientific capacity should be supported by regional and international cooperation, to ensure both equitable development and the spread and utilization of human creativity without discrimination of any kind against countries, groups or individuals. Cooperation between developed and developing countries should be carried out in conformity with the principles of full and open access to information, equity and mutual benefit. In all efforts of cooperation, diversity of traditions and cultures should be given due consideration. The developed world has a responsibility to enhance partnership activities in science with developing countries and countries in transition. Helping to create a critical mass of national research in the sciences through regional and international cooperation is especially important for small States and least developed countries. Scientific structures, such as universities, are essential for personnel to be trained in their own country with a view to a subsequent career in that country. Through these and other efforts conditions conducive to reducing or reversing the brain drain should be created. However, no measures adopted should restrict the free circulation of scientists.

36. Progress in science requires various types of cooperation at and between the intergovernmental, governmental and non-governmental levels, such as: multilateral projects; research networks, including South-South networking; partnerships involving scientific communities of developed and developing countries to meet the needs of all countries and facilitate their progress; fellowships and grants and promotion of joint research; programmes to facilitate the exchange of knowledge; the development of internationally recognized scientific research centres, particularly in developing countries; international agreements for the joint promotion, evaluation and funding of mega-projects and broad access to them; international panels for the scientific assessment of complex issues; and international arrangements for the promotion of postgraduate training. New initiatives are required for interdisciplinary collaboration. The international character of fundamental research should be strengthened by significantly increasing support for long-term research projects and for international collaborative projects, especially those of global interest. In this respect particular attention should be given to the need for continuity of support for research. Access to these facilities for scientists from developing countries should be actively supported and open to all on the basis of scientific merit. The use of information and communication technology, particularly through networking, should be expanded as a means of promoting the free flow of knowledge. At the same time, care must be taken to ensure that the use of these technologies does not lead to a denial or restriction of the richness of the various cultures and means of expression.

37. For all countries to respond to the objectives set out in this *Declaration*, in parallel with international approaches, in the first place national strategies and institutional arrangements and financing systems need to be set up or revised to enhance the role of sciences in sustainable development within the new context. In particular they should include: a long-term national policy on science to be developed together with the major public and private actors; support to science education and scientific research; the development of cooperation between R&D institutions, universities and industry as part of national innovation systems; the creation and maintenance of national institutions for risk assessment and management, vulnerability reduction, safety and health; and incentives for investment, research and innovation. Parliaments and governments should be invited to provide a legal, institutional and economic basis for enhancing scientific and technological capacity in the public and private sectors and facilitate their interaction. Science decision-making and priority-setting should be made an integral part of overall development planning and the formulation of sustainable development strategies. In this context, the recent initiative by the major G-8 creditor countries to embark on the process of reducing the debt of certain developing countries will be conducive to a joint effort by the developing and developed countries towards establishing appropriate mechanisms for the funding of science in order to strengthen national and regional scientific and technological research systems.

38. Intellectual property rights need to be appropriately protected on a global basis, and access to data and information is essential for undertaking scientific work and for translating the results of scientific research into tangible benefits for society. Measures should be taken to enhance those relationships between the protection of intellectual property rights and the dissemination of scientific knowledge that are mutually supportive. There is a need to consider the scope, extent and application of intellectual property rights in relation to the equitable production, distribution and use of knowledge. There is also a need to further develop appropriate national legal frameworks to accommodate the specific requirements of developing countries and traditional knowledge and its sources and products, to ensure their recognition and adequate protection on the basis of the informed consent of the customary or traditional owners of this knowledge.

4. Science in society and science for society

39. The practice of scientific research and the use of knowledge from that research should always aim at the welfare of humankind, including the reduction of poverty, be respectful of the dignity and rights of human beings, and of the global environment, and take fully into account our responsibility towards present and future generations. There should be a new commitment to these important principles by all parties concerned.

40. A free flow of information on all possible uses and consequences of new discoveries and newly developed technologies should be secured, so that ethical issues can be debated in an appropriate way. Each country should establish suitable measures to address the ethics of the practice of science and of the use of scientific knowledge and its applications. These should include due process procedures for dealing with dissent and dissenters in a fair and responsive manner. The World Commission on the Ethics of Scientific Knowledge and Technology of UNESCO could provide a means of interaction in this respect.

41. All scientists should commit themselves to high ethical standards, and a code of ethics based on relevant norms enshrined in international human rights instruments should be established for scientific professions. The social responsibility of scientists requires that they maintain high standards of scientific integrity and quality control, share their knowledge, communicate with the public and educate the younger generation. Political authorities should respect such action by scientists. Science curricula should include science ethics, as well as training in the history and philosophy of science and its cultural impact.

42. Equal access to science is not only a social and ethical requirement for human development, but also essential for realizing the full potential of scientific communities worldwide and for orienting scientific progress towards meeting the needs of humankind. The difficulties encountered by women, constituting over half of the world's population, in entering, pursuing and advancing in a career in the sciences and in participating in decision-making in science and technology should be addressed urgently. There is an equally urgent need to address the difficulties faced by disadvantaged groups which preclude their full and effective participation.

43. Governments and scientists of the world should address the complex problems of poor health and increasing inequalities in health between different countries and between different communities within the same country with the objective of achieving an enhanced, equitable standard of health and improved provision of quality health care for all. This should be undertaken through education, by using scientific and technological advances, by developing robust long-term partnerships between all stakeholders and by harnessing programmes to the task.

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44. We, participants in the World Conference on Science for the Twenty-first Century: A New Commitment, commit ourselves to making every effort to promote dialogue between the scientific community and society, to remove all discrimination with respect to education for and the benefits of science, to act ethically and cooperatively within our own spheres of responsibility, to strengthen scientific culture and its peaceful application throughout the world, and to promote the use of scientific knowledge for the well-being of populations and for sustainable peace and development, taking into account the social and ethical principles illustrated above.

45. We consider that the Conference document *Science Agenda – Framework for Action* gives practical expression to a new commitment to science, and can serve as a strategic guide for partnership within the United Nations system and between all stakeholders in the scientific endeavour in the years to come.

46. We therefore adopt this *Declaration on Science and the Use of Scientific Knowledge* and agree upon the *Science*

Agenda – Framework for Action as a means of achieving the goals set forth in the *Declaration*, and call upon UNESCO and ICSU to submit both documents to the General Conference of UNESCO and to the General Assembly of ICSU. The United Nations General Assembly will also be seized of these documents. The purpose is to enable both UNESCO and ICSU to identify and implement follow-up action in their respective programmes, and to mobilize the support of all partners, particularly those in the United Nations system, in order to reinforce international coordination and cooperation in science.

Introductory Note to the Science Agenda – Framework for Action

The present document was prepared by the Conference Secretariat with the aim of facilitating the understanding of the *Science Agenda*; it was not presented for endorsement by the Conference.

THE NEW CONTEXT

1. Several major factors have transformed, and will continue to affect, the relationships between science and society as they have developed in the second half of the 20th century.

(a) Scientific research is increasing our knowledge and ability to understand complex systems and processes in an ever-wider range of scales in space and time. The natural sciences are enjoying a highly creative phase stemming from breakthroughs and advances in various fields, from molecular biology and biochemistry, quantum physics and materials science to the planetary sciences and astronomy. The emergence of new disciplines and of interactions among them, increasingly powerful computational tools, the rapid accumulation of scientific knowledge, and the need to bring together the natural and the social sciences in joint agendas, are having strong implications for scientific research and education.

(b) The conditions for the production and sharing of scientific knowledge are themselves changing as a consequence of the increasing intensity of communication, the growing interface between disciplines and tighter interactions between science and technology, universities and industry, laboratories and factories. Major economic and social implications are arising from the closer contacts between scientific discoveries and their application, technological know-how and commercial exploitation. Information and communication technologies are causing changes on all fronts as profound as those brought about when print first appeared.

(c) Linked to the changes occurring in science and technology are the globalization of trade and business, the growing role of transnational firms, and a reduction in the capacities of governments to regulate economic activity and its repercussions on society. Within a framework that is increasingly subject to transnational challenges and short-term requirements, competitive businesses are often those that can capture information flows and apply them quickly, rather than produce discoveries and inventions themselves.

(d) The end of the Cold War has resulted in a significant reorientation of investment in science and technology in some countries. For the most industrialized ones, resources dedicated to defence research during this period had represented a major part of public R&D expenditure. Unfortunately, in recent years, the percentage of GNP devoted to international cooperation, particularly with developing countries, has – with certain exceptions – stagnated or decreased. Taken together with economic difficulties, the result has been little or no growth worldwide in non-business funding for fundamental research, while business R&D has declined in some sectors as a natural consequence of the stagnation of the global economy. At the same time, research programmes, especially large ones designed to address global problems, are subject to increasing costs.

(e) Growing inequalities on all fronts that contribute to new tensions and conflicts today beset the world. The patterns of disparities are now more complex and more contrasted. As one of many instances that illustrate this situation on a global scale, we recall that 20% of humankind share 86% of the total private consumption. Within and between countries the benefits of education, culture, health services and other factors of human and social well-being are ever more unequally distributed. On the whole, while the industrially more developed nations have built up a strong capacity for scientific research and technological innovation, other countries – the majority – have yet to meet basic needs of their populations, and the least developed countries are struggling for survival. The varying degrees to which countries and regions adapt to the scientific and technological changes threaten to further accentuate inequalities in access to and production of scientific knowledge and technical know-how.

(f) A further major factor is the multiplication of the environmental problems that weigh on the future of our planet. Beyond the phenomena of population growth and increasing urbanization, industrial, agricultural and transport activities are bringing about a major transformation of the global environment with serious consequences for human health and the productivity of ecosystems. Human action has even started to affect the functioning of global life support systems such as the climate system. The need to adopt the precautionary principle, initiate anticipatory research, take preventive action, and indeed make sustainability an essential ingredient in any model of development has become more evident at a time when societies, cultures, economies and environments are becoming increasingly interdependent.

(g) The need to take into account ethical consequences when discussing future directions of science has become more urgent over the last few years, requiring an open debate within the scientific community and in society at large. In this context, scientists themselves have started to play an active role in defining and accepting their ethical responsibilities. Public understanding and awareness of science are important factors in the establishment of appropriate ethical guidelines and procedures.

(h) A feature of our times is the emergence of organized sectors of society demanding participation in democratic debates and decision-making, as well as transparency on all public issues. Alongside traditional actors, such as trade unions and political parties, strong new groups are coming to the fore, including the communication media, citizen movements, and a variety of non-governmental organizations, such as associations of parliamentarians, industrial professions and entrepeneurs. Many of these are concerned with the environmental and other issues that the sciences are expected to address. Some reflect a lay disenchantment and disregard for science, and a fear of the unforeseen or unknown consequences of some of its applications. The confusion about who speaks for science among the many sectors, and whose science can be trusted, adds to this public mistrust.

(i) Women as a majority of the world population are claiming an increased role in all activities, particularly in science and technology. Important institutional and cultural barriers that prevent the progress of women in science education and research and their taking on responsibilities on a par with men, need still to be removed. Achieving a better gender balance in scientific activities, itself being a strong desideratum for reasons of equity, also implies that the approach, and even the content, of scientific advances may change to focus more on the needs and aspirations of humankind.

2. There is today an accumulation of discoveries, applications and know-how that constitute an unprecedented source of knowledge, information and power. Never have discoveries and innovations promised a greater increase in material progress than today, but neither has the productive – or destructive – capacity of humankind left unresolved so many uncertainties. The major challenge of the coming century lies in the ground between the power which humankind has at its disposal and the wisdom which it is capable of showing in using it.

3. Guided by the conviction that it is both urgent and possible to take up this challenge, the participants to the Conference are determined to concentrate efforts on the production and sharing of knowledge, know-how and techniques to address the major problems ahead – whether local, regional or global. It is evident to everyone today, however, that it is not science alone that will solve the problems. A new relationship needs to be built between those who create and use scientific knowledge, those who support and finance it, and those concerned with its applications and impacts; such are the essence and the spirit of the new commitment.

4. In considering the practical expressions of this commitment, it must be recognized that the relationship between scientific research, education, technological innovation and practical benefits is much more diverse and complex today than in the past, and frequently involves many players other than researchers. The progress of science cannot be justified purely in terms of search for knowledge. In addition, it must be defended – and increasingly so, in view of budgetary restrictions – through its relevance and effectiveness in addressing the needs and expectations of our societies.

5. Democratic decision-making on scientific matters requires participation of all groups of society. It also needs consideration and respect for national diversity, within a spirit of solidarity and cooperation. If only one sector of the population or a single group of nations has an active role in science and its applications, disequilibria are likely to occur, and the gaps and disparities tend to increase. Therefore, in defining and carrying out the multilateral commitment to science it is not only important that each and every country be able to make its own informed and articulate contribution, but also that all actors – the public, the media, scientists, educators, industrialists, politicians and decision-makers – be involved in the process.

THE NEW COMMITMENT

6. In the process leading to the World Conference on Science and to the drafting of the *Declaration on Science and the Use of Scientific Knowledge* and the *Science Agenda – Framework for Action*, numerous reflections and enlightening debates have taken place. Among the wide variety of concerns and proposals expressed, there are clear signals of convergence with regard to some central issues. These are listed here as general guidelines to facilitate the identification of the new commitment.

(a) Need for drastic changes of attitude and approach to problems of development, especially to their social, human and environmental dimension. The sciences must be put to work for sustainable peace and development in a progressively responsive and democratic framework; scientists, as all other stakeholders, must correspondingly recognize their ethical, social and political responsibilities.

(b) Need to improve, strengthen and diversify science education, formal and non-formal, at all levels and for all sectors, and to integrate science into the general culture, emphasizing its contribution to the formation of open and critical thinking as well as to the improvement of people's ability to meet the challenges of modern society. Any discriminatory barrier operating against equitable participation in science must be removed, and positive efforts are needed to fully integrate women into the sciences.

(c) Need to strengthen the national science and technology (S&T) base, refurbishing national science policies, increasing scientific personnel and ensuring a stable and supportive research context, especially in areas of local and global relevance. In developing countries increased funding for S&T is needed, taking into account local capacities and priorities, and this funding should be augmented by similar commitments from developed partners.

(d) Need to break traditional barriers between the natural and the social sciences and to adopt interdisciplinarity as a common practice. Moreover, since the processes underlying present global problems and challenges need the concurrence of all scientific disciplines, it is imperative to attain a proper balance in their support.

(e) Need to open scientific matters to public debate and democratic participation, so as to arrive at consensus and concerted action. The scientific community is expected to open itself to a permanent dialogue with society. A dialogue with other forms of knowledge and expressions of culture is particularly relevant.

(f) Need to reinforce and broaden scientific cooperation, regional and international, through networking and institutional arrangements with intergovernmental organizations (IGOs), non-governmental organizations (NGOs), research and education centres. In this regard, the programmes of UNESCO and ICSU must be strengthened, in particular through cooperation between them and with other UN bodies. It is a challenge to improve the coordination of the various efforts of these partners, respecting their different roles and stimulating synergy between them.

BASIS FOR ACTION

The following text takes up all sections of the draft *Science Agenda – Framework for Action* and attempts to provide the general ideas behind the guidelines for action listed therein.

1. Science for knowledge; knowledge for progress

1.1 Role of fundamental research

7. The sciences are expected to continue to fulfil their intrinsic assignment which is the acquisition of knowledge and understanding, benefiting from the creativity of scientists around the world. This is the central argument for continuing to carry out fundamental research and education in all disciplines of the sciences.

8. Public authorities, private companies, universities, research laboratories and institutes have each their own dynamics and domains of action. In being associated with all such different partners, scientific research must cope with the underlying diversity of contexts and adopt a coherent agenda, establishing a balance between immediate and long-term objectives.

9. In designing international policies and programmes for science, the multiplicity of conditions for scientific research, of perceptions of science, and also of problems, needs and possibilities to apply scientific knowledge must be borne in mind. International science is ideally built upon the plurality and diversity of contributions that all nations can make to the scientific endeavour, in regard to their own capacities, needs and interests.

1.2 The public and private sectors

10. Fundamental research requires sustained public support, as it represents an ‘off-market’ public asset with uncertain short-term profitability. The returns and applications deriving from it provide, in turn, new irrigation for the entire research system, while at the same time contributing to the solution of specific problems and the development of technological competencies.

11. New funding mechanisms must be sought for science, taking into account the present context. In most industrialized countries private investment in S&T research surpasses that financed by the public sector, and a number of public institutions have been or are being privatized. Agencies awarding grants tend to give preference to research with short-term goals, and accountability of results is increasingly based on technological applications and patents rather than on basic knowledge acquisition. In the majority of developing countries, on the other hand, most scientific research is publicly financed. Even in those countries that have managed to build up a critical mass of scientists, the private sector gives preference to research with short-term goals or does not invest in research at all; the scientific system is weakly linked to the productive system and local industry does not benefit from the opportunities created by science; as a result, S&T contributes little to the creation of national wealth in these countries.

1.3 Sharing scientific information and knowledge

12. The new communication and information technologies have become an important factor of change, giving rise to new directions, methodologies and scenarios for scientific work and new ways of producing, accessing and using information. The growing impact and potential of the new technologies make it necessary for scientists and institutions to adapt themselves in order to fully benefit from the advantages they can bring. In this regard it is essential that they be developed and used to provide equal opportunities for scientists in different regions of the world, to facilitate the wide distribution and access of information, and to promote a truly international scientific dialogue. Computing and information systems that are reflective of the diverse cultures, languages, technical resources, habits and needs of people around the world, need to be designed.

13. True and comprehensive sharing of scientific knowledge cannot be accomplished by electronic means alone. Regional and international networks for research and training, partnerships involving communities of developed and developing countries, and specific programmes for the exchange and transfer of scientific knowledge and skills, have proved to be important mechanisms and should be fostered and implemented more widely.

2. Science for peace and development

2.1 Science for basic human needs

14. Food, water, shelter, access to health care, social security and education are cornerstones of human well-being. Poverty and dependence affecting a number of countries can only be escaped through social and economic transformation and political determination, a comprehensive and upgraded educational system, and the appropriate development and use of science and technology. Scientific knowledge needs to be applied to find ways of reducing the imbalance, injustice and lack of resources that particularly affect the marginalized sectors of society and the poorer countries in the world.

15. Science is today a currency in the hierarchy of nations. Developing countries need to enhance S&T capacities in areas that are relevant to the problems of their own populations and to their national development. It should not be overlooked, however, that these countries present a very mixed profile, some being in various ways closer to the industrialized world than to their fellow countries. It is essential that each country has the capacity and takes on the responsibility to define its priorities and areas of relevance and how to address them.

16. It is against this background that a case for supporting S&T in developing countries is made. Such an effort will benefit these countries in solving their actual problems and achieving more healthy and sustained development. In essence, it will be of global benefit, since there are more than 120 developing countries, comprising three-quarters of the global population. As long as these countries are not effectively involved in science, can we talk of ‘world science’?

17. There is need for urgency here. Comprehensive, far-reaching and lasting development is a universal challenge and is not restricted to a particular group of countries. It requires coherent, plural, multifaceted action, to which the international community has much to contribute.

2.2 Science, environment and sustainable development

18. One of the greatest challenges facing the world community in the next century will be the attainment of sustainable development, calling for balanced interrelated policies aimed at economic growth, poverty reduction, human well-being, social equity and the protection of the Earth's resources, commons and life-support systems. It is increasingly perceived that sustainable management and use of resources and sustainable production and consumption patterns in general, are the only pathways to meeting developmental and environmental needs of present and future generations. We must enhance and harness our scientific capabilities to develop sustainably.

19. Taking into account the Programme for the Further Implementation of Agenda 21 adopted by the UN General Assembly in 1997, the guidelines for action provided in the *Agenda* are expected to address the following key objectives: to strengthen capacity and capability in science for sustainable development, with particular emphasis on the needs of developing countries; to reduce scientific uncertainty and improve the long-term prediction capacity for the prudent management of environment-development interactions; to foster international scientific cooperation and the transfer and sharing of scientific knowledge; to bridge the gap between science, the productive sectors, decision-makers and major groups in order to broaden and strengthen the application of science.

2.3 Science and technology

20. Science, technology and engineering are among the principal drivers of industrial and economic development. The difference in abilities of countries to exploit S&T through the process of innovation contributes to an ever-increasing extent to differences in economic performance and to the widening income gap between industrialized and developing countries.

21. Innovation in all sectors is increasingly characterized by bi-directional feedback between the basic research system, and technology development and diffusion. This is changing the requirements for successful technology transfer and upgrading of innovation capabilities in the developing countries, with implications for domestic policies and international cooperation. One of their main priorities must now be to promote the development of national scientific and technological infrastructures and of the corresponding human resources.

2.4 Science education

22. There is an urgent need to renew, expand and diversify basic science education for all, with emphasis on scientific and technological knowledge and skills needed to participate meaningfully in the society of the future. The rapid advancement of scientific knowledge means that the established education system cannot alone cope with the changing needs of the population at the various levels; increasingly, formal education must be complemented through non-formal channels. The communication media and technologies can play an important role in this regard. On a broader scale, an increasingly scientifically oriented society needs science popularization in its widest sense, to promote an improved understanding of science and adequately orient public perceptions and attitudes about science and its applications.

23. It is today widely recognized that, without adequate higher S&T education and research institutions providing a critical mass of skilled scientists, no country can ensure genuine development. It is further agreed that action at national level should aim to tighten the links between higher education and research institutions, taking into account that education and research are closely related elements in the establishment of knowledge.

2.5 Science for peace and conflict resolution

24. There can be no lasting peace as long as essential problems of development are not properly attended to; there can be no proper development as long as the culture and the practice of peace are not universally adopted. Were science always geared towards peaceful purposes, it certainly would make a greater contribution to the well-being of humankind.

25. Constructing the defences of peace in the minds of individuals, as recommended in the preamble of UNESCO's Constitution, implies grasping the tools of scientific knowledge to reveal, understand and at the same time prevent the root causes of conflict. This field of research requires the concerted effort of a large number of scientific disciplines, involving as it does issues such as social inequality, poverty, food provision, justice and democracy, education for all, health care and environmental degradation. In other words, it involves every aspect of economic, social or political life that engenders violence.

26. The contribution to the construction of the defences of peace entails a great responsibility for all professionals active in science and technology. The principles of universality, freedom and critical thinking that are dear to science, constitute a common bond for a constructive dialogue between parts in conflict and serve to fight intolerance and ideological and social barriers. Scientists have demonstrated the role that they can play in addressing conflicts and preparing peaceful agreements; this role must continue, with the support of governments and independent institutions.

2.6 Science and policy

27. Each country needs to have the capacity to design and implement its own science policy with responsibility within the global context, and to confront the dilemmas of priorities and competition for resources from the particular phase of economic development and industrialization in which it finds itself. A balanced development of a science base suitable for the country's needs requires an elaborate infrastructure and a stable institutional support, as well as the existence of an appropriate legal and regulatory framework. Regional and international networking and cooperation can facilitate the exchange of national experiences and the design of more coherent science policies. Requiring special attention are the legal issues and regulations guiding international research and development in strategic areas such as information and communication technologies, biodiversity and biotechnology. Cooperation among international organizations is needed, to improve the measurement and understanding of intangible assets and recognition of their importance and to protect the output of intangible investments in areas such as intellectual property rights. An internationally accepted framework should provide for the protection of intellectual property rights, recognizing the provisions in existing frameworks that allow for different approaches.

28. In view of the increasing complexity of decision-making in the contemporary world, scientists should be more proactive in their contribution to national policy-making. The role of science in society and governance has never been more important. Science has an over-riding responsibility to help societies make a transition to a dynamically stable and sustainable ecological and economic system. In this transition, an alliance between modern technical science and the holistic wisdom from traditional societies and philosophers from all cultures can be very important.

3. Science in society and science for society

3.1 Social requirements and human dignity

29. Science should be at the service of humanity as a whole, and contribute to improving the quality of life for every member of present and future generations. Those fields that promise to address issues of social interest need therefore to be high on the agenda. When dealing with science-society benefits, long-term vision in scientific planning is necessary, provided that intermediate objectives are defined so that appropriate evaluation can be undertaken. Different individuals, sectors or groups can have widely varying needs and requirements, according to parameters such as: age, education, health, professional training, working place, living place, economic status, gender and cultural background. Identifying these diverse needs, and finding possible ways to address and fulfil them, require the concerted effort of scientists from different disciplines. The new reciprocal commitment between science and society will require not only that the scientific community take account of these challenges, but also that the cooperation mechanisms be resolute in promoting a strategy to meet them.

30. The scientific community, governments, and all relevant institutions are urged to commit themselves to unrestricted respect for social and human dignity. In compliance with an essential social and moral duty, scientists should always work for the democratic principles of dignity, equality and respect of individuals and against ignorance, prejudice and the exploitation of human beings.

3.2 Ethical issues

31. The new discoveries and applications of science, while raising enormous hopes and expectations, also give rise to a variety of ethical problems; scientists, therefore, cannot any more overlook the ethical implications of scientific work. Ethics is a subject for permanent debate, choices and commitments – both at the individual and the social level – that transcends juridical prescriptions and adapts itself to a diversity of evolving situations.

32. The full and free exercise of science, with its own values, should not be seen to conflict with the recognition of spiritual, cultural, philosophical and religious values; an open dialogue needs to be maintained with these value systems to facilitate mutual under-standing. For the development of an all-encompassing debate on ethics in science, and a possibly ensuing code of universal values, it is necessary to recognize the many ethical frameworks in the civilizations around the world.

3.3 Widening participation in science

33. All human beings have the right to participate in the scientific enterprise. Equity in entering and pursuing a career in science is one of the social and ethical requirements of human development; there should be no discrimination in science, against any sector or individual. The increasing participation or involvement of all sectors of society in the scientific enterprise entails a systemic revision of science; it is clear that the decision-making and normative mechanisms of the institution of science are inevitably affected. In particular, any kind of central monitoring, whether political, ethical or economic, needs to take into account the increasingly diverse actors entering into the social tissue of science.

34. Women's participation in the planning, orientation, and assessment of scientific research and education activities needs urgently to be increased, in order to benefit from their perspective on science and their contribution to it; only in this way can maximum use be made of the intellectual potential of humankind as a whole and the optimal contribution to human and social well-being ensured.

3.4 Modern science and other systems of knowledge

35. Modern science does not constitute the only form of knowledge, and closer links need to be established between this and other forms, systems and approaches to knowledge, for their mutual enrichment and benefit. A constructive inter-cultural debate is in order, to help find ways of better linking modern science to the broader knowledge heritage of humankind.

36. Traditional societies, many of them with strong cultural roots, have nurtured and refined systems of knowledge of their own, relating to such diverse domains as astronomy, meteorology, geology, ecology, botany, agriculture, physiology, psychology and health. Such knowledge systems represent an enormous wealth. Not only do they harbour information as yet unknown to modern science, but they are also expressions of other ways of living in the world, other relationships between society and nature, and other approaches to the acquisition and construction of knowledge. Special action must be taken to conserve and cultivate this fragile and diverse world heritage, in the face of globalization and the growing dominance of a single view of the natural world as espoused by science. A closer linkage between science and other knowledge systems is expected to bring important advantages to both sides.

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Annex to the Introductory Note

The *Declaration on Science and the Use of Scientific Knowledge* and the *Science Agenda – Framework for Action* took into account the decisions, recommendations and reports of a number of recent major intergovernmental or non-governmental conferences, listed below, as well as the reports of associated meetings organized within the framework of the World Conference on Science.

- Recommendation on Status of the Scientific Researchers, adopted by the UNESCO General Conference, Paris, 1974
- Vienna Programme of Action on Science and Technology for Development (UNCSTD), UN, New York, 1979
- ICSU/ICASE/UNESCO International Conference on Science Education, Bangalore, 1985
- ICSU Statement on Freedom in the Conduct of Science, Paris, 1989
- World Conference on Education for All: Meeting Basic Learning Needs (Final Report), Jomtien, 1990
- WMO/UNEP/UNESCO/ICSU Second World Climate Conference, Geneva, 1990
- Statement of the International Conference on an Agenda of Science for Environment and Development into the 21st Century (ASCEND 21), Vienna, 1991
- Agenda 21 of the United Nations Conference on Environment and Development, Rio de Janeiro, 1992
- Conference on Academic Freedom and University Autonomy, Sinaia, 1992
- ICSU Statement on Gene Patenting, Paris, 1992
- World Conference on Human Rights, Vienna, 1993
- Report of the Global Conference on the Sustainable Development of Small Island Developing States, Bridgetown, Barbados, 1994
- Agenda for Development adopted by the Group of 77 in New York, 18 April 1995
- World Summit for Social Development, Copenhagen, Denmark, 1995
- Report of the Gender Working Group on Gender Implications of Science and Technology for the Benefit of Developing Countries of the United Nations Commission on Science and Technology, 1995
- Fourth World Conference on Women, Beijing, 1995
- International Congress on Education and Informatics, Moscow, 1996
- ICSU Statement on Animal Research, Paris, 1996
- World Food Summit, Rome, 1996
- Programme for the Further Implementation of Agenda 21, UN General Assembly, New York, 1997
- World Congress on Higher Education and Human Resources Development for the Twenty-First Century, Manila, 1997
- *Universal Declaration on the Human Genome and Human Rights*, adopted by the UNESCO General Conference, Paris, 1997
- *World Declaration on Higher Education for the Twenty-First Century: Vision and Action*, UNESCO, Paris, 1998
- Framework for Priority Action for Change and Development of Higher Education, UNESCO, Paris, 1998

Science Agenda – Framework for Action

Preamble

1. We, participants in the World Conference on Science for the Twenty-First Century: A New Commitment, assembled in Budapest, Hungary, from 26 June to 1 July 1999 under the aegis of the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the International Council for Science (ICSU), state the following:

2. Advancing the objectives of international peace and the common welfare of humankind is one of the highest and most noble goals of our societies. The creation of UNESCO and of ICSU, more than half a century ago, was a symbol of the international determination to advance these objectives through scientific, educational and cultural relations among the peoples of the world.

3. The above objectives are as valid now as they were 50 years ago. However, while the means of achieving them have developed considerably over this half-century through scientific and technological progress, so have the means of threatening and compromising them. In the meantime, the political, economic, social, cultural and environmental context has also changed profoundly, and the role of the sciences (natural sciences such as physical, earth and biological sciences, biomedical and engineering sciences, social and human sciences) in this changed context needs to be collectively defined and pursued: hence the grounds for a new commitment.

Having adopted the *Declaration on Science and the Use of Scientific Knowledge*, and inspired by the *Introductory Note to the Science Agenda – Framework for Action*,

4. We agree, by common consent, to the present *Science Agenda – Framework for Action*, as guidelines and instruments for action to achieve the goals proclaimed in the *Declaration*.

5. We consider that the guidelines for action formulated hereafter provide a framework for dealing with the problems, challenges and opportunities confronting scientific research and for the furthering of existing and new partnerships, both national and international, between all actors in the scientific endeavour. Such research efforts and partnerships must be consistent with the needs, aspirations and values of humankind and respect for nature and future generations, in the pursuit of lasting peace, equity and sustainable development.

1. Science for knowledge; knowledge for progress

6. We commit ourselves to the advancement of knowledge. We want this knowledge to be at the service of humanity as a whole, and to produce a better quality of life for present and future generations.

1.1 Role of fundamental research

7. Each country should aim at having high-quality scientific institutions capable of providing research and training facilities in areas of specific interest. In those cases where countries are unable to create such institutions, the necessary support should be granted by the international community, through partnership and cooperation.

8. The conduct of scientific research should be supported by an appropriate legal framework at the national and international level. Freedom of opinion and protection of intellectual rights are particularly important in this respect.

9. Research groups and institutions and relevant non-governmental organizations should strengthen their regional and international cooperation activities, with a view to: facilitating scientific training; sharing expensive facilities; promoting the dissemination of scientific information; exchanging scientific knowledge and data, notably between developed and developing countries; and jointly addressing problems of global concern.

10. Universities should ensure that their programmes in all fields of science focus on both education and research and the synergies between them and introduce research as part of science education. Communication skills and exposure to social sciences should also be a part of the education of scientists.

11. In the new context of increased globalization and international networking the universities are faced not only with new opportunities but also with challenges. For example, universities play an increasingly important role in the innovation system. Universities are responsible for educating a highly skilled workforce for the future and equipping their students with the capabilities needed to deal with global issues. They should also be flexible and regularly update their knowledge. Universities in developed and developing countries should intensify their cooperation, for example through twinning arrangements. UNESCO could act as a clearing house and facilitator.

12. Donor countries and agencies of the United Nations system are urged to foster cooperation in order to improve the quality and efficiency of their support to research in developing countries. Their joint effort should be focused on strengthening national research systems, taking into account national priorities and science policies.

13. Professional organizations of scientists, such as national and international academies, scientific unions and learned societies, have an important role to play in the promotion of research, for which they should be given wide recognition and corresponding public support. Such organizations should be encouraged to further international collaboration on questions of universal concern. They should also be encouraged to be the advocates of the freedom of scientists to express their opinions.

1.2 The public and private sectors

14. Through participatory mechanisms involving all relevant sectors and stakeholders, governments should identify the needs of the nation and give priority to support for the public research needed to achieve progress in the various fields, ensuring stable funding for the purpose. Parliaments should adopt corresponding measures and levels of budget appropriation.

15. Governments and the private sector should achieve an adequate balance between the various mechanisms for funding scientific research, and new funding possibilities should be explored or promoted through appropriate regulation and incentive schemes, with public-private partnerships based on flexible schemes, and governments guaranteeing the accessibility of generated knowledge.

16. There should be close dialogue between donors and recipients of S&T funding. Universities, research institutes and industry should develop closer cooperation; financing of S&T projects should be promoted as a means of advancing knowledge and strengthening science-based industry.

1.3 Sharing scientific information and knowledge

17. Scientists, research institutions and learned scientific societies and other relevant non-governmental organizations should commit themselves to increased international collaboration, including the exchange of knowledge and expertise. Initiatives to facilitate access to scientific information sources by scientists and institutions in the developing countries should be especially encouraged and supported. Initiatives to fully incorporate women scientists and other disadvantaged groups from the South and North into scientific networks should be implemented. In this context efforts should be made to ensure that results of publicly funded research will be made accessible.

18. Countries that have the necessary expertise should promote the sharing and transfer of knowledge, in particular through support to specific programmes set up for the training of scientists worldwide.

19. The publication and wider dissemination of the results of scientific research carried out in the developing countries should be facilitated, with the support of developed countries, through training, the exchange of information and the development of bibliographic services and information systems better serving the needs of scientific communities around the world.

20. Research and education institutions should take account of the new information and communication technologies, assess their impact and promote their use, for example through the development of electronic publishing and the establishment of virtual research and teaching environments or digital libraries. Science curricula should be adapted to take into account the impact of these new technologies on scientific work. The establishment of an international programme on Internet-enabled science and vocational education and teaching, alongside the conventional system, should be considered in order to redress the limitations of educational infrastructure and to bring high-quality science education to remote locations.

21. The research community should be involved in regular discussion with the publishing, library and information technology communities to ensure that the authenticity and integrity of scientific literature are not lost with the evolution of the electronic information system. The dissemination and sharing of scientific knowledge are an essential part of the research process, and governments and funding agencies should therefore ensure that relevant infrastructure and other costs are adequately covered in research budgets. Appropriate legal frameworks are necessary as well.

2. Science for peace and development

22. Today, more than ever, the natural and social sciences and their applications are indispensable to development. Worldwide cooperation among scientists is a valuable and constructive contribution to global security and to the development of peaceful interactions among different nations, societies and cultures.

2.1 Science for basic human needs

23. Research specifically aimed at addressing the basic needs of the population should be a permanent chapter in every country's development agenda. In defining research priorities, the developing countries and countries in transition should consider not only their needs and weaknesses in terms of scientific capacity and information, but also their own strengths in terms of local knowledge, know-how and human and natural resources.

24. For a country to have the capacity to provide for the basic needs of its population, science and technology education is a strategic necessity. As part of this education, students should learn to solve specific problems and to address the needs of society by utilizing scientific and technological knowledge and skills.

25. Industrialized countries should cooperate with developing countries through jointly defined S&T projects that respond to the basic problems of the population in the latter. Careful impact studies should be conducted to ensure better planning and implementation of development projects. Personnel engaged in such projects should receive training of relevance to their work.

26. All countries should share scientific knowledge and cooperate to reduce avoidable ill-health throughout the world. Each country should assess and so identify the health improvement priorities that are best suited to their own circumstances. National and regional research programmes aimed at reducing variations in health among communities, such as collecting good epidemiological and other statistical data and communicating corresponding best practice to those who can use it, should be introduced.

27. Innovative and cost-effective mechanisms for funding science and pooling the S&T resources and efforts of different nations should be examined with a view to their implementation by relevant institutions at the regional and international levels. Networks for human resources interchange, both North-South and South-South, should be set up. These networks should be so designed as to encourage scientists to use their expertise for the benefit of their own countries.

28. Donor countries, non-governmental and intergovernmental organizations and United Nations agencies should strengthen their programmes involving science to address pressing developmental problems as indicated in this *Science Agenda* while maintaining high quality standards.

2.2 Science, environment and sustainable development

29. National, regional and global environmental research programmes should be strengthened or developed, as appropriate, by governments, concerned United Nations agencies, the scientific community and private and public research funding institutions. These research programmes should include programmes for capacity-building. Areas requiring special attention include the freshwater issue and the hydrological cycle, climate variations and change, oceans, coastal areas, polar regions, biodiversity, desertification, deforestation, biogeochemical cycles and natural hazards. The goals of the existing international global environmental research programmes should be vigorously pursued within the framework of Agenda 21 and the action plans of the global conferences. Cooperation between neighbouring countries or among countries having similar ecological conditions must be supported in the solution of common environmental problems.

30. All components of the earth system must be monitored systematically on a long-term basis; this requires enhanced support by governments and the private sector for the further development of the global environmental observing systems. The effectiveness of monitoring programmes depends crucially on the wide availability of monitored data.

31. Interdisciplinary research involving both the natural and the social sciences must be vigorously enhanced by all major actors concerned, including the private sector, to address the human dimension of global environmental change, including health impacts, and to improve understanding of sustainability as conditioned by natural systems. Insights into the concept of sustainable consumption also demand the interaction of natural sciences with social and political scientists, economists and demographers.

32. Modern scientific knowledge and traditional knowledge should be brought closer together in interdisciplinary projects dealing with the links between culture, environment and development in such areas as the conservation of biological diversity, management of natural resources, understanding of natural hazards and mitigation of their impact. Local communities and other relevant players should be involved in these projects. Individual scientists and the scientific community have a responsibility to communicate in clear language the scientific explanations of these issues and the ways in which science can play a key role in addressing them.

33. Governments, in cooperation with universities and higher education institutions, and with the help of relevant United Nations organizations, should extend and improve education, training and facilities for human resources development in environment-related sciences, also utilizing traditional and local knowledge. Special efforts in this respect are required in developing countries, with the cooperation of the international community.

34. All countries should emphasize capacity-building in vulnerability and risk assessment, early warning of both short-lived natural disasters and long-term hazards of environmental change, improved preparedness, adaptation, mitigation of their effects and integration of disaster management into national development planning. It is important, however, to bear in mind that we live in a complex world with an inherent uncertainty about long-term trends. Decision-makers must take this into account and therefore encourage the development of new forecasting and monitoring strategies. The precautionary principle is an important guiding principle in handling inevitable scientific uncertainty, especially in situations of potentially irreversible or catastrophic impacts.

35. S&T research on clean and sustainable technologies, recycling, renewable energy resources and efficient use of energy should be strongly supported by the public and private sectors at national and international levels. Competent international organizations, including UNESCO and the United Nations Industrial Development Organization (UNIDO), should promote the establishment of a freely accessible virtual library on sustainable technologies.

2.3 Science and technology

36. National authorities and the private sector should support university-industry partnerships also involving research institutes and medium, small and micro-enterprises, for promoting innovation, accelerating returns from science and generating benefits for all the participants.

37. Curricula relating to science and technology should encourage a scientific approach to problem-solving. University-industry cooperation should be promoted to assist engineering education and continuing vocational education and to enhance responsiveness to the needs of industry and support from industry to the education sector.

38. Countries should adopt best practices for advancing innovation, in a manner best suited to their needs and resources. Innovation is no longer a linear process arising from a single advance in science; it requires a systems approach involving partnerships, linkages between many areas of knowledge and constant feedback between many players. Possible initiatives include cooperative research centres and research networks, technology ‘incubators’ and research parks, and transfer and advisory bodies for small and medium enterprises. Specific policy instruments, including initiatives to encourage national innovation systems to address science-technology links, should be developed taking into account global economic and technological changes. Science policy should promote the incorporation of knowledge into social and productive activities. It is imperative to tackle the issue of the endogenous generation of technologies starting from problems faced by developing countries. This implies that these countries should have resources available to become generators of technologies.

39. Acceleration of technology transfer to promote industrial, economic and social development should be supported through the mobility of professionals between universities and industry and between countries, as well as through research networks and inter-firm partnerships.

40. Greater emphasis should be placed by governments and institutions of higher learning on engineering, technological and vocational education, also in the form of lifelong learning and through the means of international cooperation. New curriculum profiles which are consistent with the requirements of employers and attractive to youth should be defined. In order to mitigate the adverse impact of asymmetric migration of trained personnel from the developing to the developed countries and also to sustain high-quality education and research in developing countries, UNESCO could catalyse more symmetric and closer interaction of S&T personnel across the world and the establishment of world-class education and research infrastructure in the developing countries.

2.4 Science education

41. Governments should accord the highest priority to improving science education at all levels, with particular attention to the elimination of the effects of gender bias and bias against disadvantaged groups, raising public awareness of science and fostering its popularization. Steps need to be taken to promote the professional development of teachers and educators in the face of change and special efforts should be made to address the lack of appropriately trained science teachers and educators, in particular in developing countries.

42. Science teachers at all levels and personnel involved in informal science education should have access to continuous updating of their knowledge for the best possible performance of their educational tasks.

43. New curricula, teaching methodologies and resources taking into account gender and cultural diversity should be developed by national education systems in response to the changing educational needs of societies. Research in science and technology education needs to be furthered nationally and internationally through the establishment and networking of specialized centres around the world, with the cooperation of UNESCO and other relevant international organizations.

44. Educational institutions should encourage the contribution of students to decision-making concerning education and research.

45. Governments should provide increased support to regional and international programmes of higher education and to networking of graduate and postgraduate institutions, with special emphasis on North-South and South-South cooperation, since they are important means of helping all countries, especially the smaller or least developed among them, to strengthen their scientific and technological resource base.

46. Non-governmental organizations should play an important role in the sharing of experience in science teaching and education.

47. Educational institutions should provide basic science education to students in areas other than science. They should also provide opportunities for lifelong learning in the sciences.

48. Governments, international organizations and relevant professional institutions should enhance or develop programmes for the training of scientific journalists, communicators and all those involved in increasing public awareness of science. An international programme on promotion of scientific literacy and culture accessible to all should be considered in order to provide appropriate technology and scientific inputs in an easily understandable form that are conducive to the development of local communities.

49. National authorities and funding institutions should promote the role of science museums and centres as important elements in public education in science. Recognizing the resource constraints of developing countries, distance education should be used extensively to complement existing formal and non-formal education.

2.5 Science for peace and conflict resolution

50. The basic principles of peace and coexistence should be part of education at all levels. Science students should also be made aware of their specific responsibility not to apply scientific knowledge and skills to activities which threaten peace and security.

51. Governmental and private funding bodies should strengthen or develop research institutions that carry out interdisciplinary research in the areas of peace and the peaceful applications of S&T. Each country should ensure its involvement in this work, whether at the national level or through participation in international activities. Public and private support for research on the causes and consequences of wars, and conflict prevention and resolution should be increased.

52. Governments and the private sector should invest in sectors of science and technology directly addressing issues that are at the root of potential conflicts, such as energy use, competition for resources, and pollution of air, soil and water.

53. Military and civil sectors, including scientists and engineers, should collaborate in seeking solutions to problems caused by accumulated weapon stocks and landmines.

54. A dialogue should be promoted between representatives of governments, civil society and scientists in order to reduce military spending and the orientation of science towards military applications.

2.6 Science and policy

55. National policies should be adopted that imply consistent and long-term support for S&T, in order to ensure the strengthening of the human resource base, establishment of scientific institutions, improvement and upgrading of science education, integration of science into the national culture, development of infrastructures and promotion of technology and innovation capacities.

56. S&T policies should be implemented that explicitly consider social relevance, peace, cultural diversity and gender differences. Adequate participatory mechanisms should be instituted to facilitate democratic debate on science policy choices. Women should actively participate in the design of these policies.

57. All countries should systematically undertake analyses and studies on science and technology policy, taking into account the opinions of all relevant sectors of society, including those of young people, to define short-term and long-term strategies leading to sound and equitable socio-economic development. A World Technology Report as a companion volume to the present UNESCO *World Science Report* should be considered in order to provide a balanced world opinion on the impact of technology on social systems and culture.

58. Governments should support graduate programmes on S&T policy and social aspects of science. Training in legal and ethical issues and regulations guiding international R&D in strategic areas such as information and communication technologies, biodiversity and biotechnology should be developed for scientists and professionals concerned. Science managers and decision-makers should have regular access to training and updating to cope with the changing needs of modern society in the areas of S&T.

59. Governments should promote the further development or setting up of national statistical services capable of providing sound data, disaggregated by gender and disadvantaged groups, on science education and R&D activities that are necessary for effective S&T policy-making. Developing countries should be assisted in this respect by the international community, using the technical expertise of UNESCO and other international organizations.

60. Governments of developing countries and countries in transition should enhance the status of scientific, educational and technical careers, and make determined efforts to improve working conditions, increase their capacity to retain trained scientists and promote new careers in S&T areas. Programmes should also be set up or promoted to establish collaboration with scientists, engineers and technologists who have emigrated from these countries to developed countries.

61. Governments should make an effort to use scientific expertise more systematically in policy-making addressing the process of economic and technological transformation. The contribution of scientists should be an integral part of programmes supporting either innovation or measures aimed at industrial development or restructuring.

62. Scientific advice is an increasingly necessary factor for informed policy-making in a complex world. Therefore, scientists and scientific bodies should consider it an important responsibility to provide independent advice to the best of their knowledge.

63. All levels of government should establish and regularly review mechanisms which ensure timely access to the best available advice from the scientific community drawing on a sufficiently wide range of the best expert sources. These mechanisms should be open, objective and transparent. Governments should publish this scientific advice in media accessible to the public at large.

64. Governments, in cooperation with the agencies of the United Nations system and international scientific organizations, should strengthen international scientific advisory processes as a necessary contribution to intergovernmental policy consensus-building at regional and global levels and to the implementation of regional and international conventions.

65. All countries should protect intellectual property rights, while recognizing that access to data and information is essential for scientific progress. In developing an appropriate international legal framework, World Intellectual Property Organization (WIPO), in cooperation with relevant international organizations, should constantly address the question of knowledge monopolies, and the World Trade Organization (WTO), during new negotiations of the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS), should incorporate into this Agreement tools aimed at financing the advancement of science in the South with the full involvement of the scientific community. In this regard, the international programmes of ICSU and the five intergovernmental scientific programmes of UNESCO should play a catalytic role by, inter alia, improving the compatibility of data collection and processing, and facilitating access to scientific knowledge.

3. Science in society and science for society

66. The practice of scientific research and the use of scientific knowledge should always aim at the welfare of humankind, be respectful of the dignity of human beings and of their fundamental rights, and take fully into account our shared responsibility towards future generations.

3.1 Social requirements and human dignity

67. Governments, international organizations and research institutions should foster interdisciplinary research aimed specifically at identifying, understanding and solving pressing human or social problems, according to each country's priorities.

68. All countries should encourage and support social science research to better understand and manage the tensions characterizing the relations between science and technology on the one hand, and the different societies and their institutions on the other hand. Transfer of technology should be accompanied by analysis of its possible impact on populations and society.

69. The structure of educational institutions and the design of their curricula should be made open and flexible so as to adjust to the emerging needs of societies. Young scientists should be provided with a knowledge and an understanding of social issues, and a capacity to move outside their specific field of specialization.

70. University curricula for science students should include field work that relates their studies to social needs and realities.

3.2 Ethical issues

71. The ethics and responsibility of science should be an integral part of the education and training of all scientists. It is important to instil in students a positive attitude towards reflection, alertness and awareness of the ethical dilemmas they may encounter in their professional life. Young scientists should be appropriately encouraged to respect and adhere to the basic ethical principles and responsibilities of science. UNESCO's World Commission on the Ethics of Scientific Knowledge and Technology (COMEST), in cooperation with ICSU's Standing Committee on Responsibility and Ethics of Sciences (SCRES), have a special responsibility to follow up on this issue.

72. Research institutions should foster the study of ethical aspects of scientific work. Special interdisciplinary research programmes are needed to analyse and monitor the ethical implications and means of regulation of scientific work.

73. The international scientific community, in cooperation with other actors, should foster a debate, including a public debate, promoting environmental ethics and environmental codes of conduct.

74. Scientific institutions are urged to comply with ethical norms, and to respect the freedom of scientists to express themselves on ethical issues and to denounce misuse or abuse of scientific or technological advances.

75. Governments and non-governmental organizations, in particular scientific and scholarly organizations, should organize debates, including public debates, on the ethical implications of scientific work. Scientists and scientific and scholarly organizations should be adequately represented in the relevant regulating and decision-making bodies. These activities should be institutionally fostered and recognized as part of scientists' work and responsibility. Scientific associations should define a code of ethics for their members.

76. Governments should encourage the setting up of adequate mechanisms to address ethical issues concerning the use of scientific knowledge and its applications, and such mechanisms should be established where they do not yet exist. Non-governmental organizations and scientific institutions should promote the establishment of ethics committees in their field of competence.

77. Member States of UNESCO are urged to strengthen the activities of the International Bioethics Committee and of the World Commission on the Ethics of Scientific Knowledge and Technology and ensure appropriate representation.

3.3 Widening participation in science

78. Government agencies, international organizations and universities and research institutions should ensure the full participation of women in the planning, orientation, conduct and assessment of research activities. It is necessary that women participate actively in shaping the agenda for the future direction of scientific research.

79. The full participation of disadvantaged groups in all aspects of research activities, including the development of policy, also needs to be ensured.

80. All countries should contribute to the collection of reliable data, in an internationally standardized manner, for the generation of gender-disaggregated statistics on S&T, in cooperation with UNESCO and other relevant international organizations.

81. Governments and educational institutions should identify and eliminate, from the early learning stages on, educational practices that have a discriminatory effect, so as to increase the successful participation in science of individuals from all sectors of society, including disadvantaged groups.

82. Every effort should be made to eliminate open or covert discriminatory practices in research activities. More flexible and permeable structures should be set up to facilitate the access of young scientists to careers in science. Measures aimed at attaining social equity in all scientific and technological activities, including working conditions, should be designed, implemented and monitored.

3.4 Modern science and other systems of knowledge

83. Governments are called upon to formulate national policies that allow a wider use of the applications of traditional forms of learning and knowledge, while at the same time ensuring that its commercialization is properly rewarded.

84. Enhanced support for activities at the national and international levels on traditional and local knowledge systems should be considered.

85. Countries should promote better understanding and use of traditional knowledge systems, instead of focusing only on extracting elements for their perceived utility to the S&T system. Knowledge should flow simultaneously to and from rural communities.

86. Governmental and non-governmental organizations should sustain traditional knowledge systems through active support to the societies that are keepers and developers of this knowledge, their ways of life, their languages, their social organization and the environments in which they live, and fully recognize the contribution of women as repositories of a large part of traditional knowledge.

87. Governments should support cooperation between holders of traditional knowledge and scientists to explore the relationships between different knowledge systems and to foster interlinkages of mutual benefit.

Follow-up

88. We, participants in the World Conference on Science, are prepared to act with determination to attain the goals proclaimed in the *Declaration on Science and the Use of Scientific Knowledge*, and uphold the recommendations for follow-up set out hereafter.

89. All participants in the Conference consider the *Agenda* as a framework for action, and encourage other partners to adhere to it. In so doing, governments, the United Nations system and all other stakeholders should use the *Agenda*, or relevant parts of it, when planning and implementing concrete measures and activities which embrace science or its applications. In this way, a truly multilateral and multifaceted programme of action will be developed and carried out. We are also convinced that young scientists should play an important role in the follow-up of this *Framework for Action.*

90. Taking into account the outcome of the six regional forums on women and science sponsored by UNESCO, the Conference stresses that special efforts should be made by governments, educational institutions, scientific communities, non-governmental organizations and civil society, with support from bilateral and international agencies, to ensure the full participation of women and girls in all aspects of science and technology, and to this effect to:

- promote within the education system the access of girls and women to scientific education at all levels;
- improve conditions for recruitment, retention and advancement in all fields of research;
- launch, in collaboration with UNESCO and the United Nations Development Fund for Women (UNIFEM), national, regional and global campaigns to raise awareness of the contribution of women to science and technology, in order to overcome existing gender stereotypes among scientists, policy-makers and the community at large;
- undertake research, supported by the collection and analysis of gender-disaggregated data, documenting constraints and progress in expanding the role of women in science and technology;
- monitor the implementation of and document best practices and lessons learned through impact assessment and evaluations;
- ensure an appropriate representation of women in national, regional and international policy- and decision-making bodies and forums;
- establish an international network of women scientists;
- continue to document the contributions of women in science and technology.

To sustain these initiatives governments should create appropriate mechanisms, where these do not yet exist, to propose and monitor introduction of the necessary policy changes in support of the attainment of these goals.

91. Special efforts also need to be made to ensure the full participation of disadvantaged groups in science and technology, and they should include:

- removing barriers in the education system;
- removing barriers in the research system;
- raising awareness of the contribution of these groups to science and technology in order to overcome existing stereotypes;
- undertaking research, supported by the collection of data, documenting constraints;
- monitoring implementation of and documenting best practices;
- ensuring representation in policy-making bodies and forums.

92. Although the follow-up to the Conference will be executed by many partners who will retain the responsibility for their own action, UNESCO, in cooperation with ICSU – its partner in convening the Conference – should act as a clearing house. For this purpose, all the partners should send UNESCO information about their follow-up initiatives and action. In this context, UNESCO and ICSU should develop concrete initiatives for international scientific cooperation together with relevant United Nations organizations and bilateral donors, in particular on a regional basis.

93. UNESCO and ICSU should submit the *Declaration on Science and the Use of Scientific Knowledge* and *Science Agenda – Framework for Action* to their General Conference and General Assembly respectively, with a view to enabling both organizations to identify and envisage follow-up action in their respective programmes and provide enhanced support for that purpose. The other partner organizations should do likewise vis-à-vis their governing bodies; the United Nations General Assembly should also be seized of the outcome of the World Conference on Science.

94. The international community should support the efforts of developing countries in implementing this *Science Agenda*.

95. The Director-General of UNESCO and the President of ICSU should ensure that the outcome of the Conference is disseminated as widely as possible, which includes transmitting the *Declaration* and the *Science Agenda – Framework for Action* to all countries, to relevant international and regional organizations and to multilateral institutions. All participants are encouraged to contribute to such dissemination.

96. We appeal for increased partnership between all the stakeholders in science and recommend that UNESCO, in cooperation with other partners, prepare and conduct a regular review of the follow-up to the World Conference on Science. In particular, no later than 2001, UNESCO and ICSU shall prepare jointly an analytical report to governments and international partners on the returns on the Conference, the execution of follow-up and further action to be taken.

Principles and commitments contained in the documents of the World Conference on Science

Basis for follow-up activities

In adopting the *Declaration* and the *Science Agenda* after substantial revision by all participants, the Budapest Conference established a basis for the alliance between science and society for the coming century, and defined guidelines to orient the action of the different partners involved. A summary of the basic principles and commitments contained in these documents is presented below as a practical guide. The conference participants have committed themselves to these principles and actions, and UNESCO and ICSU will actively promote their implementation.

Main principles contained in the *Declaration*

- There is an urgent need to use scientific knowledge from all fields in a responsible manner to address human needs and aspirations. The practice and use of science should always aim at the welfare of humankind, present and future.
- Fundamental and problem-oriented research are essential for achieving endogenous development.
- Appropriate education and research programmes in S&T, especially in developing countries, need sustained support from governments and the private sector.
- Science education at all levels and without discrimination is a fundamental requisite for democracy. Equality in access to science is not only a social and ethical requirement: it is a necessity for realizing the full human intellectual potential.
- Expanded science literacy, ability and skills, and an appreciation of ethical values, are needed to improve public decision-making on science issues.
- Enhanced regional and international cooperation are needed to support scientific capacity-building, especially in the small states and the least developed countries.
- New initiatives are required for interdisciplinary collaboration and for cooperation between different sectors involved in the production and use of scientific knowledge. The objective should be a move towards sustainable development strategies through integration of economic, social, cultural and environmental dimensions.
- Use of information and communication technologies for free flow of knowledge should be expanded, with due respect for the diversity of cultures and plurality of expression.
- Intellectual property rights need to be protected on a global basis. Legal frameworks should meet the specific requirements of developing countries and traditional knowledge, its sources and products.

Main commitments and activities contained in the *Science Agenda* (numbers refer to paragraphs)

Commitments to support or promote:	**by governments**	**by universities research institutions**	**by scientists and the scientific community**	**by the private sector and funding agencies**	**by NGOs and society at large**
research and new ways of funding it	7, 14, 15	10		15, 16	
research and teaching related to social needs	23, 26, 52, 67	67, 69, 70		52	
research to solve environmental problems	29, 30, 35	29	29	29, 30, 35	
interdisciplinary research and education	67	10, 31, 67	31	31	
research on the impact of technology on society	57, 61, 68				
science education	24, 41, 42, 43, 45	9, 10, 11, 20, 42, 43, 44, 47	9		46
engineering education	24, 40	40			
science communication and popularization	48, 49	10, 48		49	48
participation of women in science	41, 43, 78, 80, 81, 90	17, 43, 78, 81, 82, 90	17, 90		90
involvement of students in decision-making		44			
environmental education and ethics	33	33	73		
capacity building in disaster mitigation	34				
university-industry partnerships	36, 38, 39	16, 37, 38, 39	61	16, 36, 38, 39	
ethics of science	8, 75, 76, 77	50, 71, 72, 74	13, 50, 71, 75		75, 76
science for peaceful purposes	51, 52, 53, 54		53, 54	51, 52	53, 54
science for development	23, 28		28		
science and technology policies	8, 38, 55, 56, 57, 58, 59	58			
scientific advice for policy-makers and public sector	61, 63, 64		62, 64		
national research systems in developing countries	12, 60			12	
international cooperation	7, 26, 27, 29, 45	9, 11, 17, 27	9, 13, 17, 27	27	
scientific collaboration with developing countries	12, 18, 19, 25				
knowledge sharing and access to scientific information	15, 18	9, 17	9, 17		
scientific publishing; electronic publishing	19, 21	20, 21		21	
protection of intellectual property rights	8, 65		65		
understanding and use of traditional knowledge	33, 83, 84, 85, 86, 87	33	32		32, 85, 86
participation of disadvantaged groups	41, 81, 91	17, 79, 81, 82, 91	17, 91		91

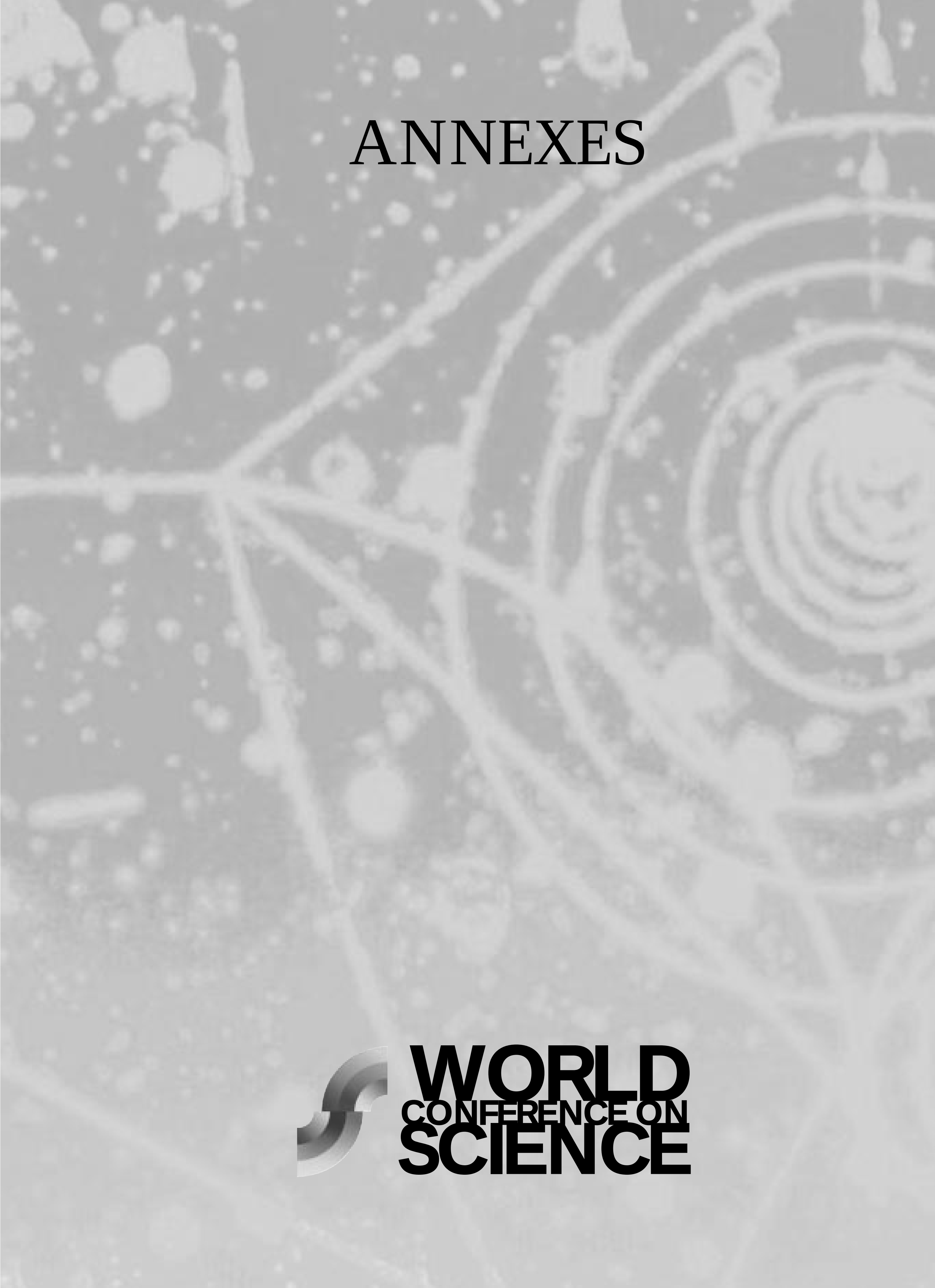
Note

Subsequent to the World Conference on Science, both the *Declaration* and the *Science Agenda* were fully endorsed by the governing bodies of ICSU and UNESCO: the 26th General Assembly of ICSU (Cairo, September 1999) and the 30th Session of the UNESCO General Conference (Paris, October/ November 1999).

In endorsing both documents, the ICSU General Assembly expressed concern over the use of the phrase 'traditional and local knowledge systems' in the texts. It acknowledged the importance of empirical knowledge built up over generations and grounded in practical evidence, but considered that such knowledge had to be distinguished from approaches that seek to promote anti-science and pseudo-science, and that degrade the values of science as understood by the ICSU community. The Assembly requested the Executive Board of ICSU to set up a critical study on the issue.

At the subsequent 30th Session of the UNESCO General Conference, representatives of Member States expressed agreement with this view, and requested UNESCO to associate itself with such a study.

ANNEXES



WORLD
CONFERENCE ON
SCIENCE

Programme of the Conference

	Morning	*Afternoon*
Saturday 26 June	Registration of participants	Plenary session: Opening ceremony Procedural matters Keynote addresses
Sunday 27 June FORUM I: Science: achievements, shortcomings and challenges	Plenary session: Keynote presentations *International NGO consultation*	Concurrent thematic meetings
Monday 28 June FORUM II: Science and society	Plenary session: Keynote presentations *International NGO consultation*	Concurrent thematic meetings
Tuesday 29 June FORUM III: Towards a new commitment – *Declaration* and *Science Agenda*	Plenary session: Participants' statements Report from FORUM I	Continuation of plenary session
Wednesday 30 June FORUM III: Towards a new commitment – *Declaration* and *Science Agenda*	Continuation of plenary session: Participants' statements Report from FORUM II *Special forum:* *International Scientific Programmes on Environment and Sustainable Development*	Continuation of plenary session
Thursday 1 July FORUM III: Towards a new commitment – *Declaration* and *Science Agenda*	Continuation of plenary session	Conclusion of plenary session: Report from Drafting Group Adoption of *Declaration* and *Science Agenda* Closing ceremony

Associated meetings

Co-organizers of the World Conference on Science, UNESCO and ICSU invited their partners to associate their own congresses and meetings with the WCS, in order to widen the process of reflection involving scientists, governments and other members of society. In all, 70 meetings were organized around the world between June 1995 and June 1999. They played a very important role in elaborating proposals and recommendations for participants of the WCS itself. In particular, the organizers of each meeting were invited to submit a report summarizing their discussions and making recommendations for consideration in the final drafting of the *Declaration* and of the blueprint for follow-up action to the WCS, the *Science Agenda*. The organizers of some 52 meetings took up the invitation.

The reports of the associated meetings marked with an asterisk (*) in the list below may be consulted at the WCS website (www.unesco.org/science/wcs) in the language(s) in which they have been submitted by the organizers of the respective events.

Africa

Science and Technology for African Development: Partnership in a Global Economy
International Symposium, Harare (Zimbabwe), 14-20 March 1998.

Technology Education and Training
International Symposium, Cape Town (South Africa), 26 June-2 July 1998.

The Development of Science and Technology in Africa* (Report)
International Conference, Durban (South Africa), 27-31 July 1998.

Sustainability and the 21st Century
Regional Symposium, Stellenbosch (South Africa), 5-9 October 1998.

First International Conference on the Role of Science and Technology in Development* (Report)
Zomba (Malawi), 7-11 December 1998.

Première Conférence des Ministres chargés de la Recherche-Développement de l'Afrique de l'Ouest et du Centre* (Rapport Final / Rapport de la réunion des experts)
Yaoundé (Cameroun), 15-16 janvier 1999.
First Conference of Ministers of Research and Development in West Africa and Central Africa* (Report of the Meeting of Experts)
Yaounde (Cameroon), 15-16 January 1999.

Femmes, science et technologie* (Rapport / *Déclaration de Ouagadougou* / Plan d'action régional)
Forum africain, Ougadougou (Burkina Faso), 25-28 janvier 1999.
Women, Science and Technology* (Report / *Ouagadougou Declaration*/ Regional Plan of Action)
African Forum, Ouagadougou (Burkina Faso), 25-28 January 1999.

Women, Science and Technology for Sustainable Human Development* (Conference Statement)
Third World Organization for Women in Science Second General Assembly and International Conference, Cape Town (South Africa), 8-11 February 1999.

Basic Sciences for Development in Eastern and Southern Africa* (*Arusha Declaration*)
International Conference, Arusha (United Republic of Tanzania), 1-3 March 1999.

Science and Technology in the SADC Region for the 21st Century* (Report)
Meeting of the Directors-General/Heads of Science and Technology in the SADC Region, Pretoria (South Africa), 20-21 April 1999.

Millennial Perspective on Science, Technology and Development in Africa and its Possible Directions for the Twenty-first Century* (*Tunis Declaration*)
Fifth General Conference of the African Academy of Sciences, Hammamet (Tunisia), 23-27 April 1999.

Arab States

Femmes, science et technologie : état des lieux et perspectives
Colloque international, Tunis (Tunisie), 20-22 novembre 1997.

Attitudes autour des sciences
Colloque, Tunis (Tunisie), 27-28 janvier 1998.

The Public Understanding of Science* (Report)
International Conference for Scientific Editors, Sharm El-Sheikh, Sinai (Egypt), 9 June 1998.

Science, Technology and Society
Conference, Beirut (Lebanon), 26-28 November 1998.

Third Arab Conference on Modern Biotechnology and Areas of Application in the Arab Countries
Cairo (Egypt), 14-17 December 1998.

Science and Technology Policies and Strategies for the 21st Century* (Report of Special Meeting on the World Conference on Science)
STEMARN Expert Group Meeting/Workshop, Beirut (Lebanon), 10-13 March 1999.

The Present Status of Scientific Research in the Arab Region
Expert Group Meeting, Beirut (Lebanon), 14-15 March 1999.

Water and Desertification in the Arab Region* (Statement)
First Arab Conference, Cairo (Egypt), 17-18 April 1999.

Regional Conference for Arab Ministers of Higher Education and Scientific Research
Riyadh (Saudi Arabia), 19 April 1999.

The Interaction of Arab Women with Science and Technology* (*Abu-Dhabi Declaration*)
Doha (United Arab Emirates), 24-26 April 1999.
Les relations entre femmes arabes, sciences et technologies* (*Déclaration d'Abu Dhabi*)
Doha (Emirats Arabes Unis), 24-26 avril 1999.

Info-Ethics
National Symposium, Cairo (Egypt), 27-28 April 1999.

Asia and Pacific

The Basic Sciences in the Service of Societies: Challenges and Opportunities for Cooperation in Central Asia* (Conclusion and Recommendations)
Regional Conference, Tashkent (Uzbekistan), 21-22 October 1998.

Priorities for Science in the 21st Century for the Asia-Pacific Region* (*Sydney Communiqué* / Summary Report of the Workshop on Women and Gender, Science, Engineering and Technology)
Regional Conference, Sydney (Australia), 1-5 December 1998.
Priorités pour la science au 21ème sciècle en Asie-Pacifique* (Resumé du Rapport de l'Atelier sur Femmes, sciences, ingénierie et technologie)
Conférence régionale, Sydney (Australie), 1-5 décembre 1998.

Second Science Centre World Congress
Calcutta (India), 11-15 January 1999.

Science and Society: a New Social Contract* (*Bangalore Communiqué*)
International Symposium, Bangalore (India), 27-29 January 1999.

NAM Meeting on World Conference on Science* (*Dhaka Communiqué*)
International Meeting, Dhaka (Bangladesh), 19-21 April 1999.

Europe and North America

Donor Support to Development-Oriented Research in the Basic Sciences* (Declaration)
International Conference, Uppsala (Sweden), 15-16 June 1995.

Basic Sciences for Development: Subregional Opportunities and Challenges* (Report)
Central European Workshop, Keszthely (Hungary), 18-20 January 1996.

Science Funds and Foundations as Essential Elements of the Research and Development Process
First European Regional Conference, Bled (Slovenia), 20-22 June 1996.

Basic Sciences for National Development Plans under Changing Economic conditions: a Sub-regional Perspective* (Report)
Second Central European Workshop, GozdtMartuljek (Slovenia), 27-28 June 1997.

Role of Scientific Foundations in Support of World Science* (Report)
International Seminar, Minsk (Belarus), 3-5 September 1997.

Possible Consequences of the Misuse of Biological Sciences* (Conclusions/Recommendations)
UNESCO International School of Science for Peace, Villa Olmo (Italy), 3-6 December 1997.

Future Scientists: – New Frontiers – Women and Men* (Report)
International Encounter of Young People, UNESCO, Paris (France), 23-24 April 1998.

Science et développement* (Sommaire)
Colloque des pays francophones, Paris (France), 13-14 mai 1998.
Science and Development* (Summary)
Symposium of French-speaking countries, Paris (France), 13-14 May 1998.

Energy Security in the Third Millenium: Scientific and Technological Issues* (Conclusions and Recommendations)
UNESCO International School of Science for Peace, Villa Olmo, Como (Italy), 14-16 May 1998.

Opportunities for International Interdisciplinary Research* (Report)
Workshop on Theoretical Nuclear/Particle Physics, Ames, Iowa (USA), 22-23 May 1998

Sciences et valeurs* (Report)
Conférence internationale, Vérone (Italie), 21-24 mai 1998.

Water: a Looming Crisis* (Report)
International Conference on World Water Resources at the Beginning of the Twenty-first Century, UNESCO, Paris (France), 3-6 June 1998.

Engineering Geology and the Environment
International Symposium of the International Association of Engineering Geology, Athens (Greece), 23-27 June 1998.

Nuclear Disarmament, Safe Disposal of Nuclear Materials or New Weapons Developments? Where are the National Laboratories going?* (Report)
UNESCO International School of Science for Peace, Villa Erba, Cernobbio-Como (Italy), 2-4 July 1998.

Climate and Water – A 1998 Perspective* (Report)
Second International Conference, Espoo (Finland), 17-20 August 1998.

Industry, Technology, Ecology – ITE '98
First International Conference, Moscow (Russian Federation), September 1998.

Russian Science on the Threshold of the 21st Century* (Report) (text in Russian and English)
International Conference, St Petersburg (Russian Federation), 17-19 September 1998.

The Discovery of Polonium and Radium – its Scientific and Philosophical Consequences. Benefits and Threats to Mankind
International Conference, Warsaw (Poland), 17-20 September 1998.

Developing Practices and Standards for Electronic Publishing in Science* (Report)
AAAS/ICSU Press/UNESCO Workshop, UNESCO, Paris (France), 12-14 October 1998.

Le rôle de la science et de la technologie dans la société et la gouvernance
Vers un nouveau contrat entre la science et la société* (Rapport)
Rencontre régionale nord-américaine, Alberta (Canada), 1-3 novembre 1998.
The Role of Science and Technology in Society and Governance
Toward a New Contract between Science and Society* (Report)
North American Regional Meeting, Alberta (Canada), 1-3 November 1998.

L'inscription sociale de la science* (Report)
Colloque européen, Paris (France), 5-6 novembre 1998.

Women in Science – Quality and Equality. Conditions for Sustainable Human Development* (Report)
European Regional Conference, Bled (Slovenia), 5-7 November 1998.

Towards Wise Coastal Development Practice
Intersectoral Workshop of Pilot Project Leaders, UNESCO, Paris (France), 30 November-4 December 1998.

Science et développement : perspectives pour le 21ème siècle* (Rapport)
Colloque international, Bruxelles (Belgique), 3-4 décembre 1998.
Science and Development: Prospects for the 21st Century* (Report)
International Symposium, Brussels (Belgium), 3-4 December 1998.

Universal Value of Fundamental Science. Science is outside of boundaries* (Address)
Meeting of National Academies of Sciences and scientific funds of countries of CIS and Eastern Europe, Minsk (Belarus), 14 January 1999.

Femmes, sciences, biotechnologies : quel avenir pour la Méditérranée?* (Rapport)
Forum international des femmes de la Méditerranée, Turin (Italie), 29-31 janvier 1999.
Women, Science, Biotechnology: What does the Future Hold for the Mediterranean?* (Report)
International Mediterranean Women's Forum, Turin (Italy), 29-31 January 1999.

The Future of Physics and Society* (Report)
International Workshop, Debrecen (Hungary), 4-6 March 1999.

Science for Survival and Sustainable Development* (Report)
Study Week of the Pontificial Academy of Science, Holy See, 12-16 March 1999.

Biotechnology and Society in the 21st Century* (Report)
International Conference, Genoa (Italy), 22-23 March 1999.

Promotion of the Role of Young People in the Development of Sciences and the Popularisation of Science Knowledge* (Report)
Third Central European Workshop, Prague (Czech Republic), 24-28 March 1999.

Un siècle de Prix Nobel. Science et Humanisme* (Projet de Déclaration Finale)
Symposium international, Paris (France), 8-10 avril 1999.
A Century of Nobel Prizes: Science and Humanism* (Draft Final Declaration)
International Symposium, Paris (France), 8-10 April 1999.

Opportunities for Partnership within the Framework of the World Conference on Science* (Joint Appeal to the World Conference on Science)
Regional Workshop, Tbilisi (Georgia), 5-7 May 1999.

Science, économie et société* (Rapport)
Conférence du Forum d'Engelberg, Paris (France), 7 mai 1999.

Science and Citizen* (Report)
International Symposium, Moscow (Russian Federation), 14-16 May 1999.

Effects of Global Business on Scientific Research* (Report)
First Internationl Conference, Geneva (Switzerland), 3-4 June 1999.

Transition to Sustainability and Forum Bled '99* (Report)
Regional European Meeting, Bled (Slovenia) 6-9 June 1999.

Implementing Ecological Integrity : Restoring Regional and Global Environmental and Human Health
International Workshop, Budapest (Hungary), 28-30 June 1999.

Latin America and the Caribbean

Sixth General Conference of the Third World Academy of Sciences
Rio de Janeiro (Brazil), 6-11 September 1997.

La Ciencia en la Integración Latinoamericana
Regional Meeting, Cancun (Mexico), March 1998.

Congrès Inter-Latin pour la Pensée Complexe* (Rapport)
Rio de Janeiro (Brazil), 8-11 septembre 1998.

Furthering Cooperation in Science and Technology for Caribbean Development* (Report)
First Caribbean Conference on Science and Technology, Port of Spain (Trinidad and Tobago), 23-25 September 1998.

Mujeres, Ciencia y Tecnología en América Latina: Diagnósticos y Estrategias* (Documento Final)
Foro Regional, Bariloche (Argentina), 21 al 23 de octubre 1998.
Femmes, science et technologie en Amérique latine : diagnostic et stratégies* (Document Final)
Colloque regional, Bariloche (Argentine), 21-23 octobre 1998.
Women, Science and Technology in Latin America: Diagnoses and Strategies* (Final Report)
Regional Symposium, Bariloche (Argentina), 21-23 October 1998.

Reunión Regional de Consulta de América Latina y del Caribe de la Conferencia Mundial Sobre la Ciencia* (Relatoría General / *Declaración de Santo Domingo*)
Santo Domingo (República Dominicana), 10 al 12 de marzo 1999.

Cooperating bodies

The following is a list of institutions and organizations that cooperated with the Conference by providing organizational or financial support.

Academia Europaea
Centre National de Recherche Scientifique (CNRS)
ICSU Committee on Science and Technology in Developing Countries (COSTED/IBN)
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World Commission on Ethics of Scientific Knowledge and Technology (COMEST)
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International Union for Pure and Applied Physics (IUPAP)
International Union of Soil Sciences (IUSS)
Leadership for Environment and Development International Inc. (LEAD)
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ICSU Programme on Capacity Building in Science (PCBS)
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ICSU Scientific Committee on Problems of the Environment (SCOPE)
ICSU Standing Committee on Responsibility and Ethics in Science (SCRES)
Third World Academy of Sciences (TWAS)
Third World Organization for Women in Science (TWOWS)
United Nations Environment Programme (UNEP)
United Nations Industrial Development Organization (UNIDO)
United Nations Development Fund for Women (UNIFEM)
United Nations University (UNU)
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The natural sciences are enjoying a highly creative phase stemming from breakthroughs and advances in various fields. The emergence of new disciplines, the increasingly powerful computational tools, the rapid accumulation of scientific knowledge and the need to bring together the natural and social sciences, are having major implications on scientific research and education.

At the same time, the regional or even global nature of many social and environmental problems makes it urgent to undertake a collective revision of the science agenda and to give a fresh impetus to international cooperation. It is a harsh reality that, while many of today's activities become global, more that 90% of research continues to be conducted in the industrialized countries and the benefits remain beyond the reach of much of humankind.

Convinced of the need for a fresh commitment to and from science, UNESCO and ICSU – the International Council for Science – convened the World Conference on Science in Budapest in June 1999, after a worldwide preparatory process of consultation. Some 1 800 representatives of government, the scientific community and other partners in science gathered in Budapest to decide what was required to make science more responsive to human and social needs and expectations and to secure public support for science education and research.

The present volume contains an edited selection of the main conference materials. Lectures and debate reports on a wide range of topics ranging from the value of fundamental research to the public perception of science, ethical issues, and new avenues for funding of science or for international cooperation, are presented, together with the 'science-society' contract unanimously approved in the form of a *Declaration on Science and the Use of Scientific Knowledge* and a *Science Agenda – Framework for Action*.

The World Conference on Science was one step in a global process which concerns us all, for we all have a moral obligation to put science and its achievements to the service of humankind and to pass on to future generations a healthy environment and conditions for a decent standard of living. Achieving these goals calls for resolute political will on the one hand, and responsible scientific research and development on the other. Scientists, representatives of civil society, members of government and policy-makers, industrialists, journalists, students – all readers alike – will find in this book a wealth of ideas, reflections, proposals and recommendations for constructive change.

Biotechnology, genetic engineering, agrobiodiversity and biosphere sustainability

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1. Science and Ethics

In order to survive, human society must progress towards a pacific and equitable social life, in accordance with the man and environment rights. Science and scientists, engaged in the advancement of knowledge and consequent benefits for human life, must be conscious and active witnesses of moral and ethic responsibilities of discoveries, inventions, innovations and technological applications. New scientific developments in basic and applied biology, chemistry, agrogenetics, geology, climatology, ecology, economics and social sciences are necessary to satisfy the basic human needs; in particular, those required by sustainable agriculture, wholesome nutrition, food production, storage and distribution.

The emphasis on the ethic dimension of science, of the scientific and technological research system promotes the trust of society and public opinion in the scientific knowledge and its derivatives.

Science is one of the main human strengths to challenge and overcome problems, conditions and limits to mankind development. Nevertheless the best science and the most effective technology will not solve societal problems and may create new ones if their development does not respect human values.

One of the main challenges is the pursuit of the biosphere sustainability, which has to be at one time socially equitable, economically pursuable and ecologically positive.

2. Agriculture, agricultural sciences and biotechnology

Agriculture is one of mankind's oldest activities. It has permitted a progressive increase in the number of humans and, therefore, a wider availability not only of purely physical strength but also of minds, intuition, wits, intellectual capacities, leading to the establishment of civilizations and cultures. The pressure of the demographic expansion and of the increasing human needs and the contemporary scientific and technological advancement are now imposing dramatic changes also on agriculture. The future of agriculture in a broad sense appears to be as a Pandora's box: rich of potentialities, problems, trends and results. Molecular biology, genetic engineering, the use of Genetically Modified Organisms (GMO) in plant and animal science, in sciences of nutrition and crop processing for food and industrial use, their effects on environment and ecosystems and their biotechnological, agrotechnological and industrial applications, are rapidly winning attention and suggesting utilizations. Socioeconomic and environmental consequences will probably be enormous and will raise scientific problems and ethical questions.

3. Problems and concerns

In the course of my address, I intend to outline first the problems and questions proposed to the human conscience and intelligence by the effects and potential advantages, but also risks, consequent to the drastic changes imposed to agriculture by the scientific research. I will then make reference to which responses are expected from science in order to mould changes into strong improvements of agricultural production and its agroindustrial processing. Agriculture could once more propose itself as an instrument of social and economic progress, a driving force of cooperation among peoples, with strong impact on the basic needs of life and freedom of human beings. Assuming that in the pursuit of scientific innovations there is no "no-risk" option, let me list, now, objective problems and concerns.

- Can food and food components from genetically modified plant and animals be harmful to human health?

- Is it feasible that GMOs transformed with DNA that increase their adaptation to agroecosystems when compared to traditional crops and livestocks, may spread their new DNA in the environment, pass it to other plants and animals wich will be endowed with new traits whose effect is unforeseeable in natural ecosystems? The recipient organisms would be wild plants and animals, which would generate a modification of biological equilibria, a threat to biodiversity and other environmental risks.

4. Thoughts and answers

Point a):

The insertion of one or few genes (carefully defined in its/their genetic information and specific properties) into a pool of about 20,000 genes, often not yet well known, which make up the genome of higher plants, invites to admit that genetic engineering is a better foreseeable and controlled method regarding the gene to be transferred, as compared to the various conventional plant breeding systems, which range from hybridization to experimentally induced mutagenesis (making the whole plant genome interact with physical and chemical mutagens). Furthermore, wholesomeness and safety of food supplies from GMOs are already controlled (of course the control system must be constantly improved) by expert committees of international agencies (e.g.: WHO, FAO and Codex Alimentarius Commission), by national bodies and agencies (e.g. Food and Drug Administration in USA) and regional institutions, as in the European Union. The European legislation, for instance, is very rigorous: it foresees the labeling of all foods containing raw materials from transgenic plants. It has also been demonstrated that, during some food preparation, due to various industrial manipulations, the DNA of transferred genes may disappear, as in the case of soybean oil extracted from seed of herbicide-resistant varieties. It is also to be reminded that toxins or antinutritional factors are present in several food crops (cassava, leguminous species etc.) and are made harmless or less toxic through food preparation. In any case, research and regulations imposing patents safeguarding Intellectual Property Rights and Farmers Rights, and stringent controls and inspections, imposing the labeling of GMO-derived products, as well as continuously updated rules on food safety, are needed in order to dispel doubts and concerns and inspire confidence to consumers.

The very same idea of substantial equivalence, of a GMO-derived food to a conventional counterpart already available as a food supply, is a dynamic concept implying a continuous and increasing assurance of the safety of GMO-derived food products.

Point b):

The chance that genes transferred into a GMO may, by accidental cross-pollination, be transmitted to other species, spontaneous or cultivated ones, possibly spontaneous species, giving origin to new plants herbicide or parasite-resistant, depends on the environmental context where the crop is grown: for instance, on the possible presence of wild species able to hybridize with the GMO. Numerous and exhaustive experiments are needed to ascertain possible cases of interbreeding and study the effects on parasite populations and on the selection of resistant mutants.

A constant monitoring is to be prescribed on the impact on ecosystems and their components. It cannot be excluded a priori that, as soon as there is a spread of the GMOs cultivation, the ability of the GMO individuals to produce compounds capable of degrading herbicides, blocking viruses, making plants more resistant to abiotic stresses, being toxic to pathogens, may be turned against other biotic components in the ecosystem (useful insects, other invertebrates, microflora and microfauna in the rhyzosphere, birds, etc.), threatening the biodiversity to a larger extent than any chemical treatment. These risks also require vast and careful research and constant monitoring, parallel to the spreading of the GMOs cultivation. In fact, new farming systems utilizing GMOs more resistant to biotic and abiotic stresses, with improved organoleptic, nutritional and market quality, must however be economically and ecologically compatible and sustainable.

A special case is represented by the use of antibiotic-resistant genes as markers in the transfer of new genes in the GM crops, and the risk that such resistances be introduced in the human food chain. In order to avoid this harmful effect, this type of markers is being eliminated, even if the origin of antibiotic-resistant mutants is also to be ascribed, since long time ago, to hospitals and veterinarian applications.

5. Considerations and conclusion

So outlined the role of research with regard to problems concerns or refusal in the introduction of the GMOs in the agrofood sector, I wish to express some ideas about ways to overcome this discrepancy. In fact, on the one hand it is possible to observe an expansion of the use of transgenic plants: their obtainment in still other crops and forest trees, an increase of acreages, a wider range of characteristics modified as for resistance to parasites, quality, productivity, adaptability to different environments, sustainability of farming systems. As a matter of fact, the use of GM crops, is now spreading from North America into other geo-political areas (South America, Far East), and is now involving also various developing Countries, with special attention to crops native to tropics or subtropics, due to the obvious advantage of a larger food availability to fight and control the malnutrition now affecting hundreds of millions of human beings.

On the other hand, a recurrent refusal to accept GMOs must be recorded, and not only in economically progressed countries. A strong public opinion and Governments concerns exist, related to fears of damages to human health, to environment and its resources, in particular biodiversity, and of possible strong disturbances to agricultural systems and commercial relationships. In this respect, clear signs of quarrels at the level of world farm products trade are already evident. It is also meaningful that those signs have manifested themselves during international meetings (Cartagena, Peru, 1999) on the application of the Convention on Biological Diversity.

Moreover, particularly important is the fact that modern societies are today better educated, or at least better informed, due to the globality and rapidity in the diffusion of information and in the action of public administrations, associations and NGOs, willing to protect the mankind and environment health. As a consequence, public opinion and policy makers and Governments must be reassured and be able to rely on a strong and ethically determined engagement of the scientific community, supported by adequate public and private investments. A strong opinion movement and a valid basic and applied research should not only aim at a control of the effects of the GM crops introduction, but also pursue the study and observation of the potentialities of the molecular biology, the genetic engineering, the biotechnologies, as in the food production, in the discovery and elimination of direct and indirect effects, both biological, and economical, and in the introduction and spreading of the GMOs in farming systems, in natural ecosystems, in the world food trade, etc. Studies and researches should not be confined, according to a reductive approach, to the monitoring of the effects determined by the introduction of the GMOs. Rather, holistic criteria should be adopted, and every reasonable hypothesis of interaction among GMOs, human beings and ecosystems investigated. Furthermore, methods adopted and results obtained should be evaluated by independent committees of experts. Full-range investigations, also denouncing risks and chances to overcome them, should be able to guarantee, beyond any reasonable doubt, the compatibility of the utilization of GMOs in agriculture and agroindustry. The public opinion, so reassured, and rationally persuaded that no technological innovation can be a "no-risk" one, would consciously be presented with by the problem of the acceptability and utility of agrobiotechnologies.

Having said that, I wish to conclude as follows:

The great multiplication of studies and research in the field of genetic engineering and agrobio-technologies must proceed at a speed parallel with the galloping spread of the introduction and trade of the GMOs.

We are in the initial phase of a new “green revolution”. As soon as genomes of cultivated plants will be completely sequenced, and investigated the function also of genes that control complex responses, favourable genes can be transfered between philogenetically distant plant species, so over coming increasing levels of micronutrients, able to syntetize pharmaceutical and nutraceutical products and raw materials for industry, with higher economic value, with better adaptation to the agroecosystems and able to detoxify environment.

Therefore, what is needed is a strong multiplying factor of research supported by public funds, by private enterprises; national and regional programs (eg: the "Quality of Life" program of the EU; the OECD plan for a biodiversity data-base global facility); by the international programs of the CGIAR and IPGRI systems, with a stronger engagements e.g. of the World and Regional Banks. Egually important will be the promotion and coordination of the UN Agencies (as FAO, UNESCO, UNDP, UNEP, WHO), as well as the increase of the North-South and South-South scientific and technological relationships. These programs must be granted the greatest attention and support. Special attention should also be given to research on the sustainability of specific agroecosystems (e.g. Mediterranean area) and to the enhancement and exploitation of tipical niche crop productions. The developed countries are particularly called to play such role, in a frame of scientific cooperation and exchange with all other countries, also through Universities, scientific Academies, Research Centers, etc. Furthermore the international corporations should be obliged to open their laboratories also to researchers from developing countries, to make their activities more transparent, to identify the most appropriate procedures of recognition and compensation of the Farmers’ Rights, as pointed out also by the Convention on Biological Diversity.

I believe that it is through this way of acting, conscious, responsible commitment of governments, scientists and public opinion, that it will be possible to realize a "synergy" among natural resources, particularly "biodiversity" and "agrobiodiversity", and "biotechnologies", which translates into an indispensable "correlation" between an equitable and solidaristic progress and the respect of the values and rights of nature and human kind.